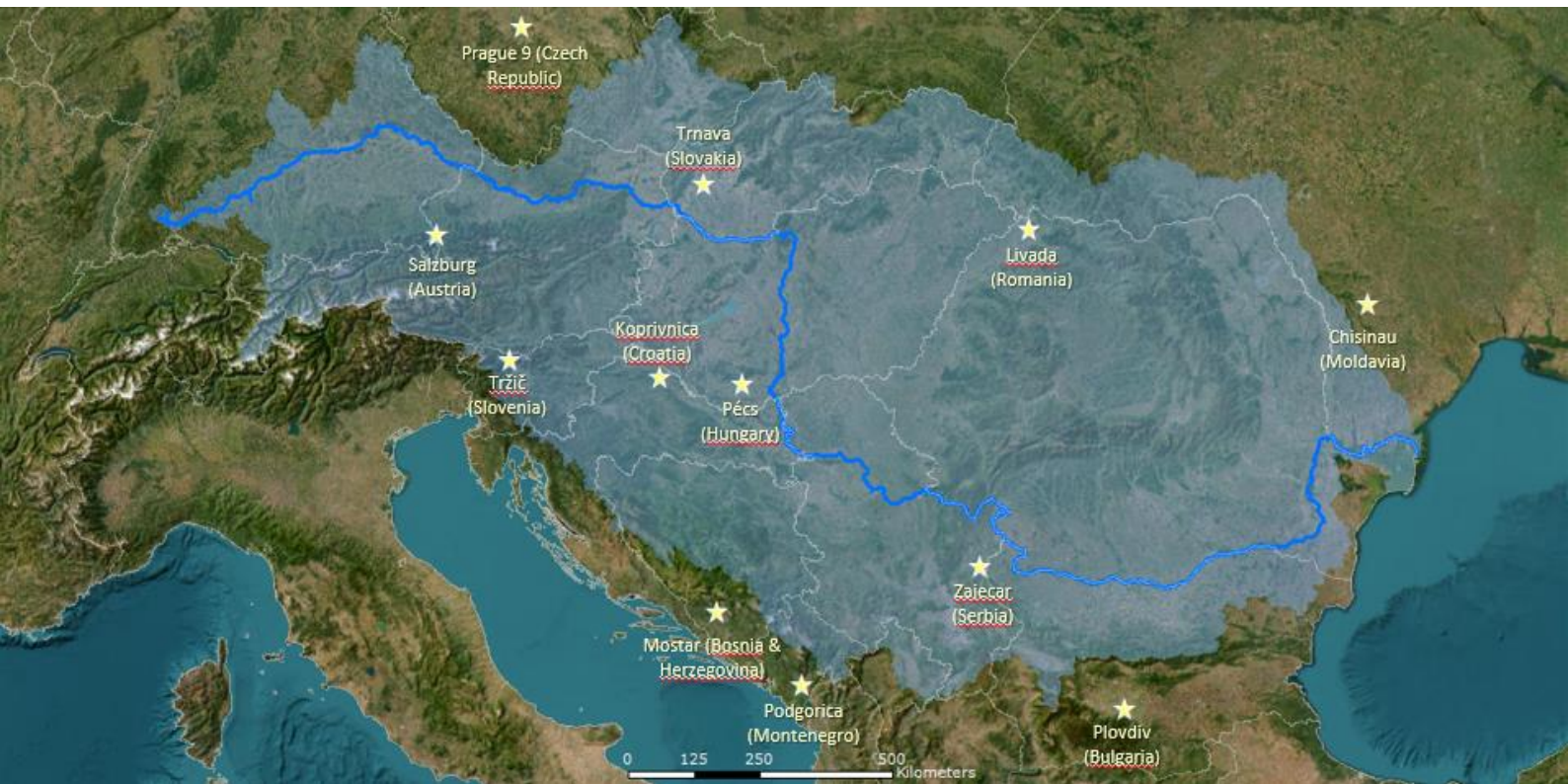


SpongeCity

Deliverable 1.2.2 Comparative study on geographical features of pilot sites



**Interreg
Danube Region**



**Co-funded by
the European Union**


SpongeCity

Copyright

Institution Paris-Lodron Universität Salzburg
Faculty Digital and Analytical Sciences
Department Department of Geoinformatics – Z_GIS
Authors Hermann Klug, Nyi Nyi Nyan Lin,
Thomas Strasser, Martin Sudmanns, Dirk Tiede
Version Version, 08.01.2025



❖ **Preface**

The project SpongeCity is about "Improving urban climate change adaptation capacities by testing and promoting the "Sponge City" methodology on transnational level". It refers to the Programme priority "A greener, low-carbon Danube Region" with its specific objective to promote climate change adaptation capacities in the Danube Region. This contributes to disaster management in relation to environmental risks. Particularly, hydro-meteorological ecosystem-based approaches are considered to adapt against flooding and water shortages such as water scarcity and droughts.

❖ Table of Contents

PREFACE	3
TABLE OF CONTENTS	4
TABLE OF FIGURES	5
TABLE OF TABLES	5
TABLE OF LISTINGS	5
1	6
2	7
2.1	7
2.2	11
3	13
3.1	14
3.2	16
3.3	17
3.4	19
3.5	20
3.6	24
3.7	27
3.8	30
4	33
5	36
LITERATURE	36
TABLE OF ABBREVIATIONS	39
INDEX	39
Table of Figures	



FIGURE 1: LOCATION OF THE PILOT SITES	7
FIGURE 2: DESIGN OF THE PILOT SITE PICTURE TOOL	11
FIGURE 3: PRECIPITATION CHARACTERISTICS	14
FIGURE 4: FLASH FLOODS ACROSS PILOT SITES.	15
FIGURE 5: WATER SHORTAGES	16
FIGURE 6: FIRE DANGER	18
FIGURE 7: SOIL TYPES	19
FIGURE 8: UNDERGROUND CONDITIONS	20
FIGURE 9: TOPOGRAPHICAL CHARACTERISATION	24
FIGURE 10: MINIMUM AND MAXIMUM ELEVATION INDICATING ELEVATION DIFFERENCE	25
FIGURE 11: POPULATION CHARACTERISTICS	27
FIGURE 12: RATIO OF SEALED TO UNSEALED SURFACES	28
FIGURE 13: EXAMPLE ENTRY FROM SALZBURG, AUSTRIA	29
FIGURE 14: PSPT USAGE STATISTICS	30
FIGURE 15: PSPT PICTURES AND CREDITS	31

❖ **Table of Tables**

TABLE 1: PILOT SITES AND THEIR CHARACTERISTICS	8
TABLE 2: CLIMATE CLASSIFICATION FOR PILOT SITES OF PAST, PRESENT AND SELECTED FUTURE SCENARIOS.	9

❖ **Table of Listings**

LISTING 1: DISTRIBUTION OF RAINFALL	13
LISTING 2: SURPLUS OF WATER	15
LISTING 3: WATER SHORTAGES	17
LISTING 4: FIRE DANGER	18
LISTING 5: UNDERGROUND CONDITIONS	20
LISTING 6: GEOLOGICAL CHARACTERISATION	21
LISTING 7: TOPOGRAPHICAL CHARACTERISTICS	25
LISTING 8: POPULATION CHARACTERISTICS	28

1 Introduction

Climate change causes the atmosphere heating up and water vapour content increasing by seven percent per degree Celsius. At the same time, the share of urban areas is increasing in Europe. Consequently, surface areas are getting continuously sealed, being impermeable for surface water. While water permeability in urban areas is heavily reduced, flash floods are impoundments in human environments (CZIGÁNY et al. 2010b). Flash floods are caused in times with surplus of rainfall while infiltration is hampered. Thus, soil texture and soil moisture play an important role causing water infiltrating or running off the surface (CZIGÁNY et al. 2010a). Consequently, transdisciplinary information about local water retention capacities is strongly required to decrease potential impacts on human, infrastructure, and environment. Thus, this project focusses on retrieving water retention information from four raingarden installations in different regions and investigates in understanding the spatial-temporal environmental settings across the Danube Region (DR). Therefore, this project is neither focussing on a screening of flash flood affected watersheds (CZIGÁNY et al. 2011) nor is it focussing on a flash flood forecast (BLÖSCHL et al. 2008).

The Sponge City approach, as a climate adaption measure, stems from China to improve their stormwater drainage system (ZHANG 2022), and to contribute to climate resilience of urban water systems (YUAN et al. 2024). Besides planning, a supply-demand analysis of sponge facilities (WANG et al. 2023), satisfaction of inhabitants are required (YANG et al. 2022). Current trends, experiences and perspectives from China (SONG 2022) might be transferred to the Danube Region. These perspectives should include multi-perspective optimisation (CHENG et al. 2024) but also multi-scale applicability (DING et al. 2023). Nature-based solution (SONG 2022) incorporating many (wetland) ecosystem services (SONG 2022) and increasing biodiversity should be considered.

To provide a scalable analysis infrastructure, Earth Observation (EO) is used to provide continuous and independent data on urban areas to support the management and monitoring of its ability to ensure water retention capacities. Timely changes on surface sealed areas, vegetation, soil, and inland water bodies can be retrieved for defined periods.

To concentrate on challenges in the DR, pilot sites have been defined to collect and investigate different demands caused by geographical and infrastructural characteristics of the pilot sites. Objectives are to identify and understand the demands, and to develop scalable user specific solutions based on the demands. This deliverable aims to compare the geographical characteristics of the selected pilot sites. Geographical details on pilot sites were collected in the Period 1 of the Interreg-funded project SpongeCity via a questionnaire (cf. D1.2.1). In a preparation step the answers were completed (if possible) and harmonized. Finally, the geographic, meteorological, hydrological, pedological, and geological characteristics are represented in a comparative format.

2 Materials and Methods

2.1 Pilot Sites

As objects of investigation, twelve (12) pilot sites have been defined in SpongeCity. These are spanning across the DR of the respective Interreg programme (Figure 1). Among the pilot sites as listed in Table 1, there are two larger cities by inhabitants (ID 1-2), four medium-sized cities (ID 3-6), and five smaller cities/districts (7-12). The pilot sites are located in the European main climates (EUROPEAN ENVIRONMENT AGENCY 2002): subtropical – intermediate, subtropical – continental, warm – transitional, warm – intermediate, and warm – continental climate conditions (CC). The pilot sites cover the biogeographical regions (BGR): Alpine, Continental, Pannonian, Steppic and Mediterranean.

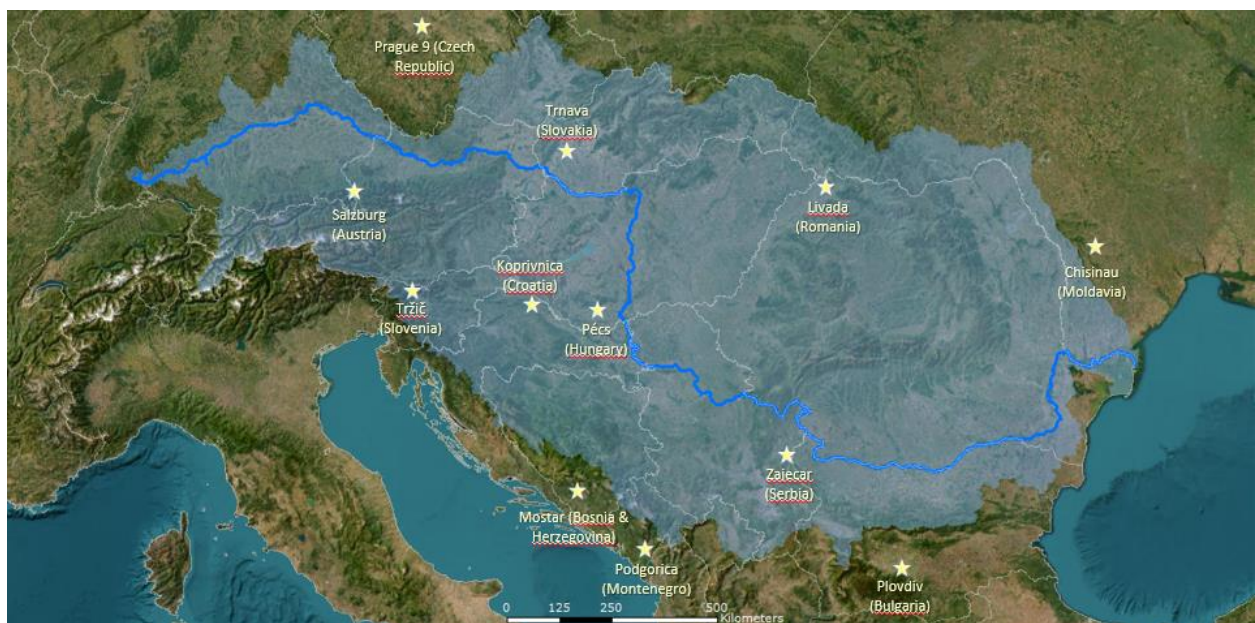


Figure 1: Location of the pilot sites

Table 1: Pilot sites and their characteristics

ID	Pilot Site Name	Number of Inhabitant	Area [km ²]	European main climates	European biogeographical regions
1	Chisinau (Moldavia)	532.513 (2014)	122,3	(7) warm – continental	Continental / Steppic
2	Plovdiv (Bulgaria)	319.612 (2021)	102,0	(3) subtropical – continental	Continental
3	Pécs (Hungary)	140.330 (2024)	163,2	(6) warm – intermediate	Pannonian
4	Salzburg (Austria)	156.619 (2023)	66,5	(5) warm – transitional	Alpine
5	Podgorica (Montenegro)	180.186 (2023)	108,0	(2) subtropical – intermediate	Mediterranean / Alpine
6	City of Mostar (Bosnia & Herzegovina)	60.195 (2013)	18,2	(2) subtropical – intermediate	Mediterranean
7	Koprivnica (Croatia)	28.580 (2021)	91,1	(6) warm – intermediate	Continental
8	Prague 9 (Czech Republic)	62.651 (2021)	13,9	(5) warm – transitional	Continental
9	Trnava (Slovakia)	62.955 (2023)	71,5	(6) warm – intermediate	Pannonian
10	City of Zajecar (Serbia)	47.991 (2022)	51,0	(7) warm – continental	Continental
11	Livada (Romania)	5.892 (2021)	116,8	(6) warm – intermediate	Continental
12	Tržič (Slovenia)	3.737 (15.011) (2022)	5,4 (155,4)	(6) warm – intermediate	Alpine

Climate is the main factor for causing floods or droughts. The CCs in regions are not constant and changing over decades. Thus, the European main climates, as a constant representation, are an initial starting point. However, they do not cover the dynamics of the hydrological conditions. The BGR inherent different landscape features. These are important for water runoff, infiltration, and storage capabilities. The BGR are based on the main climates including topographical characteristics, soil types, vegetation type, and habitats for species. These features are helpful for understanding pilot site characteristics. Considering dynamic climatic aspects, we analysed Köppen-Geiger global maps modelled by BECK et al. (2023) for each pilot site. The Köppen-Geiger classification, developed by KÖPPEN (1884) and KÖPPEN (1936) and refined by GEIGER (1954) and GEIGER (1961), represent five major classes divided in 30 sub-classes using threshold values and seasonality of monthly air temperature and

precipitation. The second version of Köppen-Geiger global maps are available with high-resolution (1 km) for periods of 30 years starting from 1901 and containing future climate change scenarios based on the shared socioeconomic pathways (SSP)(RIAH1 et al. 2017).

The pilot sites show different climate classification categories (Table 2). The categories include:

- BSk – Arid, steppe, cold
- Csa – Temperate, dry summer, hot summer
- Cfa – Temperate, no dry season, hot summer
- Cfb – Temperate, no dry season, warm summer
- Dfa – Cold, no dry season, hot summer
- Dfb – Cold, no dry season, warm summer
- Dfc – Cold, no dry season, cold summer

Table 2: Climate classification for pilot sites of past, present and selected future scenarios.

ID	Pilot Site Name	Climate classification (1961 - 1990)	Climate classification (1990 - 2020)	Climate classification (2041 – 2070, SSP2-4.5)	Climate classification (2041 – 2070, SSP3-7.0)
1	Chisinau (Moldavia)	Dfb	Dfa, Dfb	BSk, Dfa, Cfa	BSk, Cfa
2	Plovdiv (Bulgaria)	Cfa	Cfa, BSk	BSk, Cfa	BSk
3	Pécs (Hungary)	Dfb,	Cfa, Dfb, Cfb	Cfa	Cfa
4	Salzburg (Austria)	Dfb	Dfb	Cfb	Cfa, Cfb
5	Podgorica (Montenegro)	Cfa, Csa, Dfb, Cfb, Dfc	Cfa, Csa, Dfb, Cfb, Dfc	Cfa, Csa, Dfb, Cfb	Cfa, Csa, Dfb, Cfb
6	Mostar (Bosnia & Herzegovina)	Cfa	Cfa	Cfa	Cfa
7	Koprivnica (Croatia)	Dfb	Cfa, Cfb	Cfa	Cfa
8	Prague 9 (Czech Republic)	Dfb	Cfb	BSk, Cfa, Cfb	BSk, Cfa
9	Trnava (Slovakia)	Dfb	Cfb, Dfb	Cfa	Cfa
10	Zajecar (Serbia)	Dfb, Dfa, BSk	Cfa, Dfb, Dfa	Cfa	Cfa
11	Livada (Romania)	Dfb	Dfb	Cfa	Cfa
12	Tržič (Slovenia)	Dfb, Dfc	Dfb, Dfc	Dfb, Cfa, Cfb	Dfb, Cfa, Cfb

2.2 Methods

A survey on the geographical characteristics (**Survey 1**) obtaining local expert knowledge refers to features such as meteorological, hydrological, pedological and geological information related to each pilot site. This information helps understanding the regional setting according to surplus or shortages of water. The information from the survey in synthesis with the "Sponge City Toolbox" should be used to design tailored climate change adaptation and management measures against flash floods (surplus of water) and storage facilities in case of water shortages. Discovering existing or to be stimulated ecosystem services should lead to functionalities adapting to potential flooding and/or mudslides and heat stress in urban areas and their surroundings. This focusses on a synthesis of multifunctional services in space and time to increase biodiversity, and to safe infrastructure and life of people, animals, and plants.

In cooperation with project partner PP1 Pécs and PP2 KCVODE questions and related choice of answers were developed in a text document (D121_SpongeCity_Survey1_Template_PLUS.docx). The survey developed in the first reporting period contained four sections with altogether 15 questions. After a review of all pilot site partners, the survey was transferred to an online interface using Microsoft Forms ([developer link](#)). This enabled pilot site partners to access the survey using an ordinary web browser ([public link](#)). Nine out of twelve partners answered the Microsoft Forms survey. Two submitted their findings text based. The city of Trnava is still missing. PLUS updated the missing entries from web searches where possible. The original results were exported to "D121_SpongeCity_Survey1_Results_PLUS.xlsx".

In the first period the answers of the questionnaire were completed (if possible) in a preparation phase. In the second period the survey results were harmonized for standardized comparison and reviewed by plausibility. Finally, the results are categorised in charts and tables and evaluated by expert interpretation.

The design of Survey 1 (geographical characteristics) and Survey 2 (infrastructural characteristics) in reporting period 1 were complemented by a Pilot Site Picture Tool (PSPT). The tool uses ArcGIS Online and is built on the ArcGIS Survey123 toolset (Figure 1).

SpongeCity - Pilot Site Representati...
Overview
Design
Collaborate
Analyze
Data
Settings

Add
Edit
Appearance
Options

SpongeCity - Pilot Site Representation (Survey123)

This survey is designed to enable taking and visualising pictures within the SpongeCity pilot sites. An online map will automatically capture all picture from all twelve pilot site and provide an overview of the conditions across the Danube River Basin.

> [Survey Result Map with pictures](#)
 > [Sponge City Sen2Cube Website](#)

1 Name of the pilot site*

Please check the pilot site the picture is referring to!

<input type="radio"/> Chisinau	<input type="radio"/> Plovdiv	<input type="radio"/> Pécs
<input type="radio"/> Salzburg	<input type="radio"/> Podgorica	<input type="radio"/> Mostar
<input type="radio"/> Koprivnica	<input type="radio"/> Prague 9	<input type="radio"/> Nagyszombat
<input type="radio"/> Zajecar	<input type="radio"/> Livada	<input type="radio"/> Tržič

2 Picture*

Please take a picture best representing a part of your pilot site with your mobile phone.

Drop image here or select image

3 Picture Credits*

Provide your first name and last name.

Text, number, date, and time

Singleline text	Multiline text
Number	Slider
Date	Time
Date and time	Email
Website	Barcode

Choice

Single select	Multiple select
Single select grid	Dropdown
Likert scale	Rating
Ranking	

Location

Map	Address
Location list	

Media and files

Image	File upload
Audio	Signature

Saved
Preview
Published

Figure 2: Design of the pilot site picture tool

3 Results of the Geographical Survey

Geographical characteristics refer to the natural and human-made features that define a specific location, area, or region on Earth. These characteristics can be divided into two main categories: a) physical and b) socio-economic geographical features.

- a) **Physical geographical characteristics** are the natural features of a region, including e.g.:
- ❖ **Climate:** The typical long-term weather patterns, including temperature, precipitation, humidity, and seasons, which vary depending on latitude, altitude, and proximity to water bodies.
 - ❖ **Landforms** as the shape and structure of the Earth's surface, such as mountains, valleys, plains, plateaus, hills, and deserts formed by various natural processes.
 - ❖ **Water bodies:** Rivers, lakes, seas, oceans, and other bodies of water that influence the climate, economy, and lifestyle of a region.
 - ❖ **Soil:** The types, fertility and permeability of soils, which impact agriculture, vegetation, and water flows.
 - ❖ **Vegetation:** The types of occurring plants and formed ecosystems, such as forests, grasslands, or deserts, influenced by climate and terrain, and playing a significant role in water retention functionalities.
 - ❖ **Natural resources:** The availability of resources like minerals, forests, fossil fuels, and water, which can influence the economy and development of a region.
- b) **Socio-economic geographical characteristics:** These features relate to the influence of human activity on the landscape and include:
- ❖ **Population:** The distribution, density, and demographic composition of people in a region.
 - ❖ **Urbanization:** The development of cities, towns, and infrastructure, which can impact land use, transportation, surface sealing and (hot/wet) living conditions.
 - ❖ **Cultural characteristics:** The cultural, agricultural, and hydrological practices including traditions of the people in a region.
 - ❖ **Political boundaries:** The lines that define regions, countries, or territories, affecting governance and jurisdiction.
 - ❖ **Economic activities:** The types of industries, agriculture, trade, and services that dominate the area, often influenced by the region's physical geography.

Together, these characteristics shape the identity of a place and influence how people live, work, and interact with their environment. KLUG AND JENEWEIN (2010) indicated that the only constat in landscape is change. These changes might also be introduced through politics. In relation to SpongeCity a few laws, directives, communications, recommendations, and strategies are important:

- ❖ European Climate Law (EUROPEAN PARLIAMENT 2021)
- ❖ EU Climate Adaptation Strategy (European Commission 2021)
- ❖ EU Biodiversity Strategy (EUROPEAN COMMISSION 2024b)
- ❖ EU Water Framework Directive (PARLIAMENT 2000)
- ❖ European Green Deal (EUROPEAN COMMISSION 2024a)
- ❖ Nature Restoration Law (EUROPEAN PARLIAMENT 2024)
- ❖ Habitat Directive (COUNCIL OF THE EUROPEAN UNION 1992)
- ❖ European Sustainability Reporting Standards (EFRAG 2022)
- ❖ Framework to facilitate sustainable investment, and amending Regulation (EUROPEAN PARLIAMENT 2020)
- ❖ EU Green Infrastructure Strategy (EUROPEAN COMMISSION 2013) with special emphasis on the water sector.
- ❖ Urban Waste Water Treatment Directive (COUNCIL OF THE EUROPEAN UNION 1991)

Dependent on the local circumstances, people might be more/less prone to disasters stemming from too less/much water. In comparison across the Danube River Basin (DRB), there might be (dis-)similarities across the pilot sites, which should be distinguished as follows.

3.1 Distribution of rainfall

The pilot sites show different amount of average annual precipitation (Figure 3). The climate varies across the DR. The annual precipitation is not only an indicator, how wet the different areas are, but also how adapted the soils are for water infiltration and storage. The pilot site face different heavy rainfall events in the last 30 years (Listing 1).

Listing 1: Distribution of rainfall

Average Annual Precipitation (mm/yr)

0 – 500 mm: Chisinau, Plovdiv

500 – 1000 mm: Zajecar, Prague 9, Pécs, Trnava, Livada, Koprivnica and adjoin settlements

1000 – 1500 mm: Salzburg, Tržič, Mostar, Podgorica

Most Heavy Rainfall Periods (30 yrs)

1995 – 2000: Prague 9

2000 – 2005: Trnava, Salzburg

2005 – 2010: Plovdiv, Tržič

2010 – 2015: Zajecar, Pécs, Koprivnica and adjoin settlements, Mostar

2015 – 2020: Chisinau, Podgorica

2nd Most Heavy Rainfall Periods (30 yrs)

1990 – 2000: Zajecar

2010 – 2015: Chisinau, Prague 9, Pécs, Trnava, Salzburg, Mostar, Podgorica

2015 – 2020: Plovdiv

2020 – 2024: Koprivnica and adjoin settlements, Tržič

3rd Most Heavy Rainfall Periods (30 yrs)

2000 – 2005: Trnava

2005 – 2010: Zajecar

2010 – 2015: Plovdiv, Prague 9, Koprivnica and adjoin settlements, Mostar, Podgorica

2015 – 2020: Salzburg, Tržič

2020 – 2024: Chisinau, Pécs

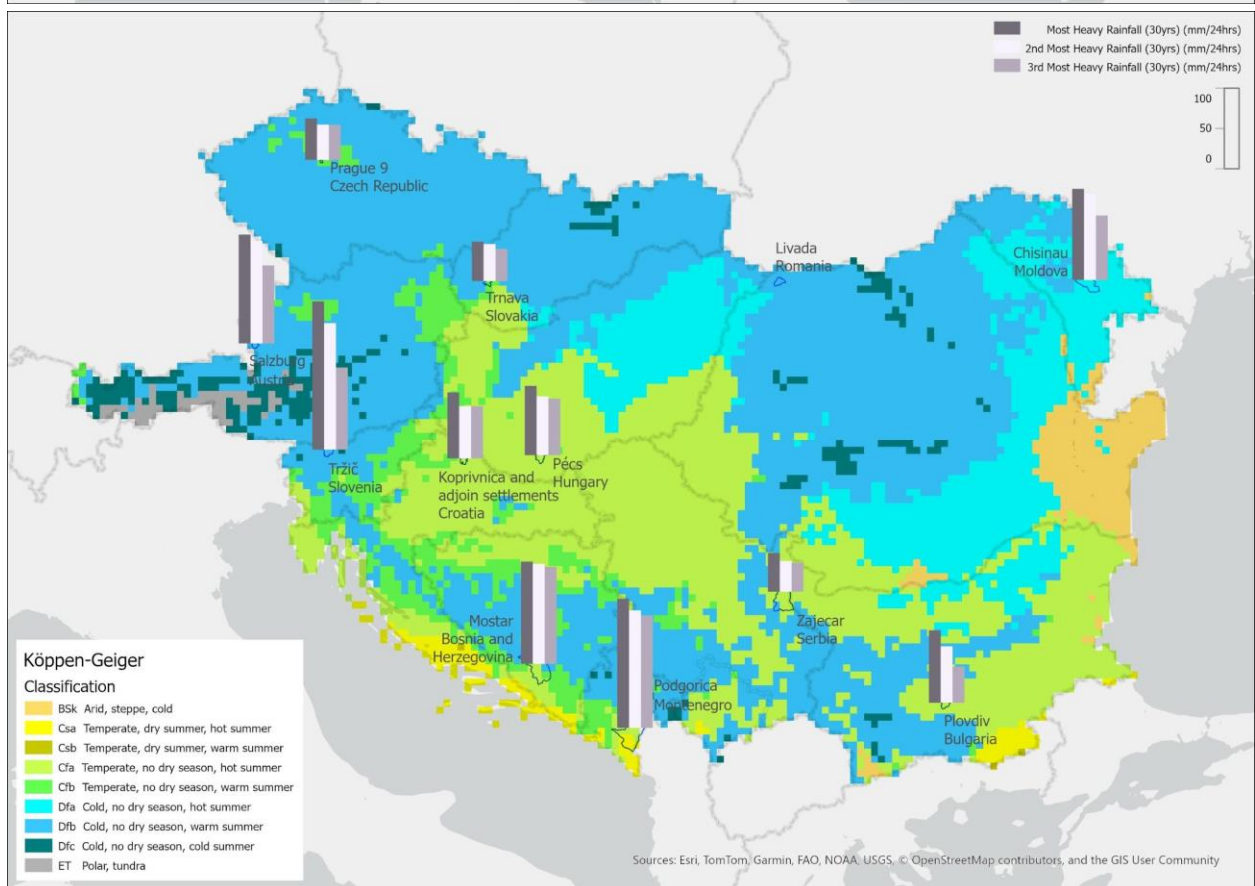
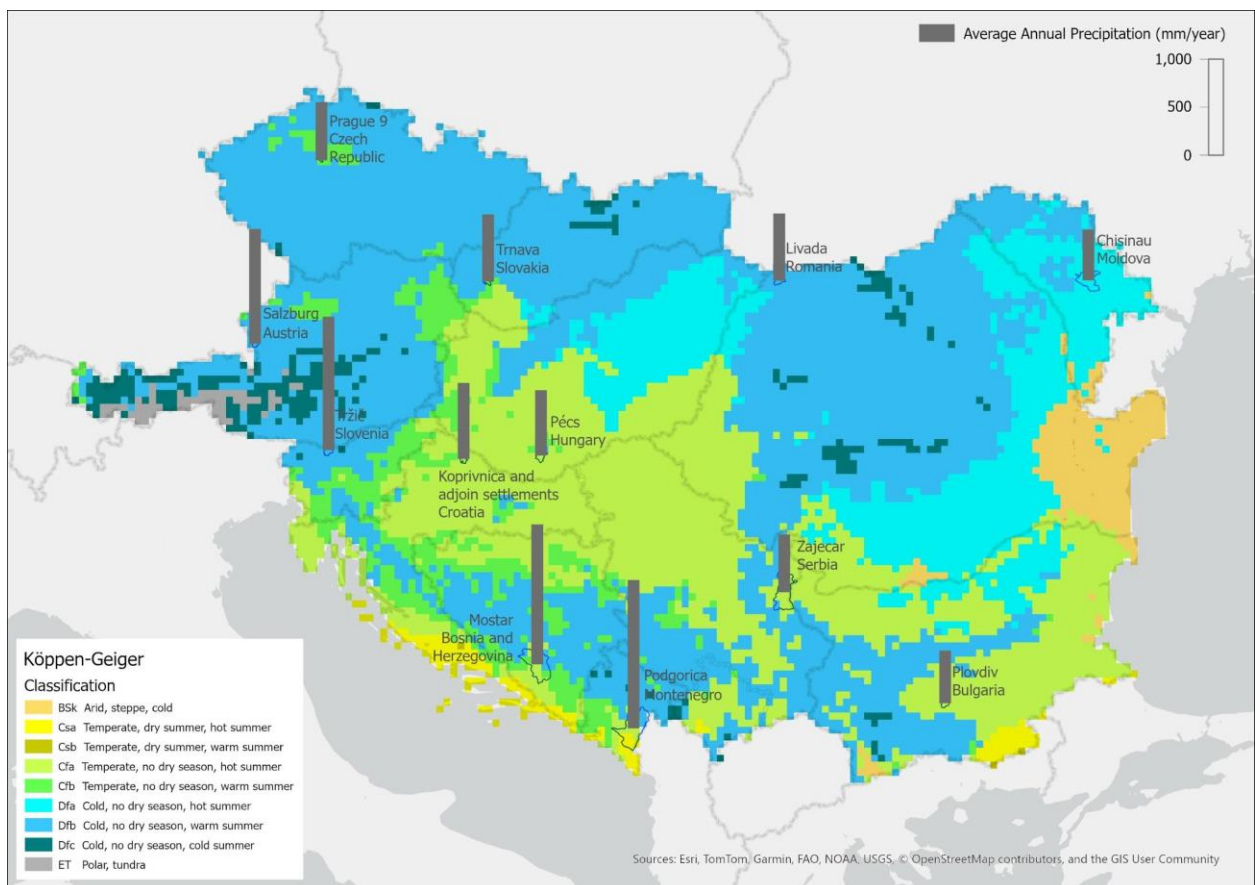


Figure 3: Precipitation characteristics

3.2 Floodings

The uneven distribution of precipitation could lead to water shortages or flooding. Some of the pilot sites have been challenged more than five times by flooding during the past 30 years (Figure 4, Listing 2). Livada was never affected by floodings.

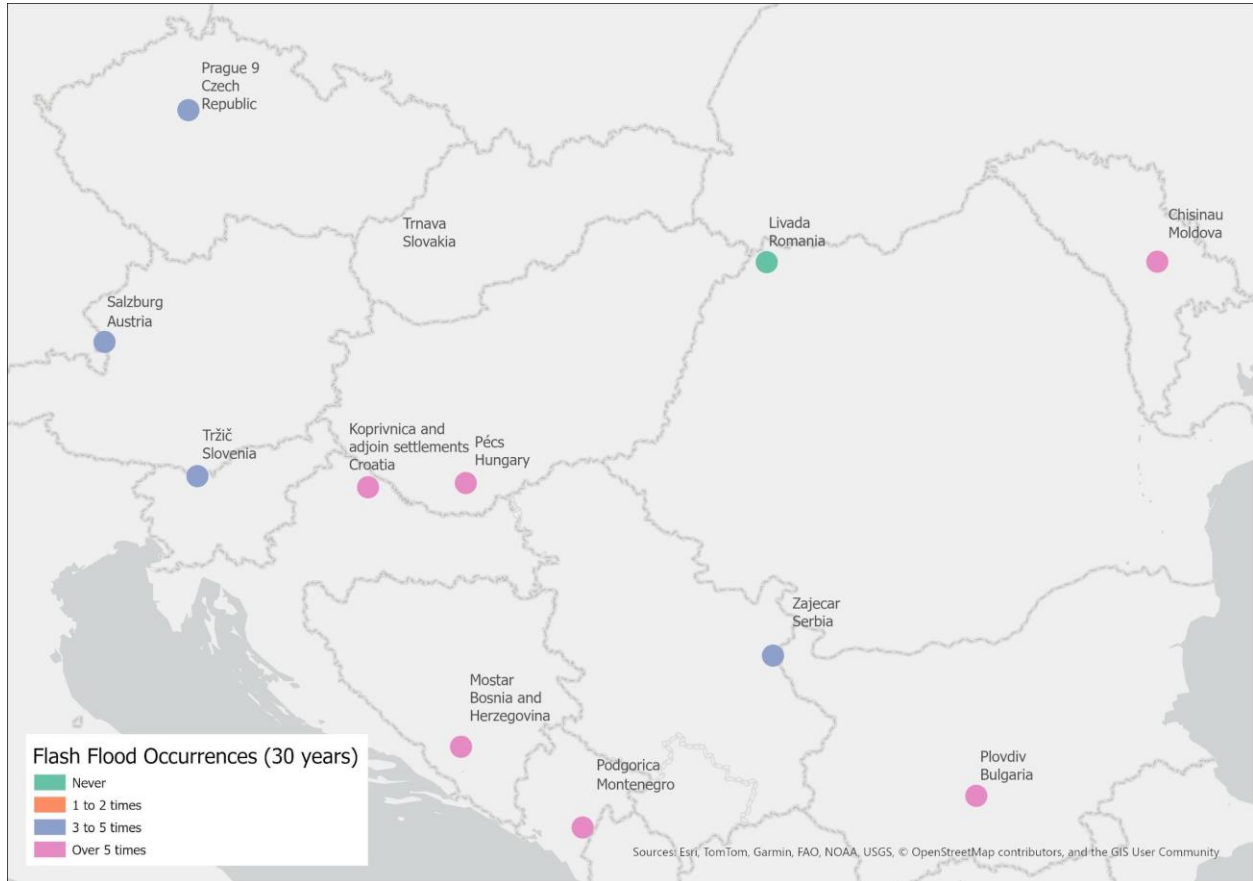


Figure 4: Flash floods across pilot sites.

Listing 2: Surplus of water

Flash Flood Occurrences (30yrs)

Over 5 times: Mostar, Podgorica, Plovdiv, Pécs, Koprivnica and adjoin settlements, Chisinau

Between 3 and 5 times: Zajecar, Tržič, Prague 9, Salzburg

Never: Livada

No Data: Trnava

Flash Flood Probabilities

Very High: Salzburg, Tržič, Chisinau, Pécs

High: Podgorica, Koprivnica and adjoin settlements, Mostar, Plovdiv

Moderate: Prague 9, Zajecar

Low: Livada

No Data: Trnava

3.3 Water Shortages

Water shortages are becoming apparent when inhabitants and/or tourists in a region are suffering from fresh water (KLUG et al. 2012). Related water resources management approaches have been developed by the Alpine Space Programme Project "AlpWaterScarce" (HOHENWALLNER et al. 2011a; HOHENWALLNER et al. 2011b). For the DRB water scarcity was relevant for Mostar, Podgorica, Plovdiv, Chisinau, Prague and Livada (Figure 5). Due to climate change most of the pilot sites will be affected by water scarcity and / or droughts.

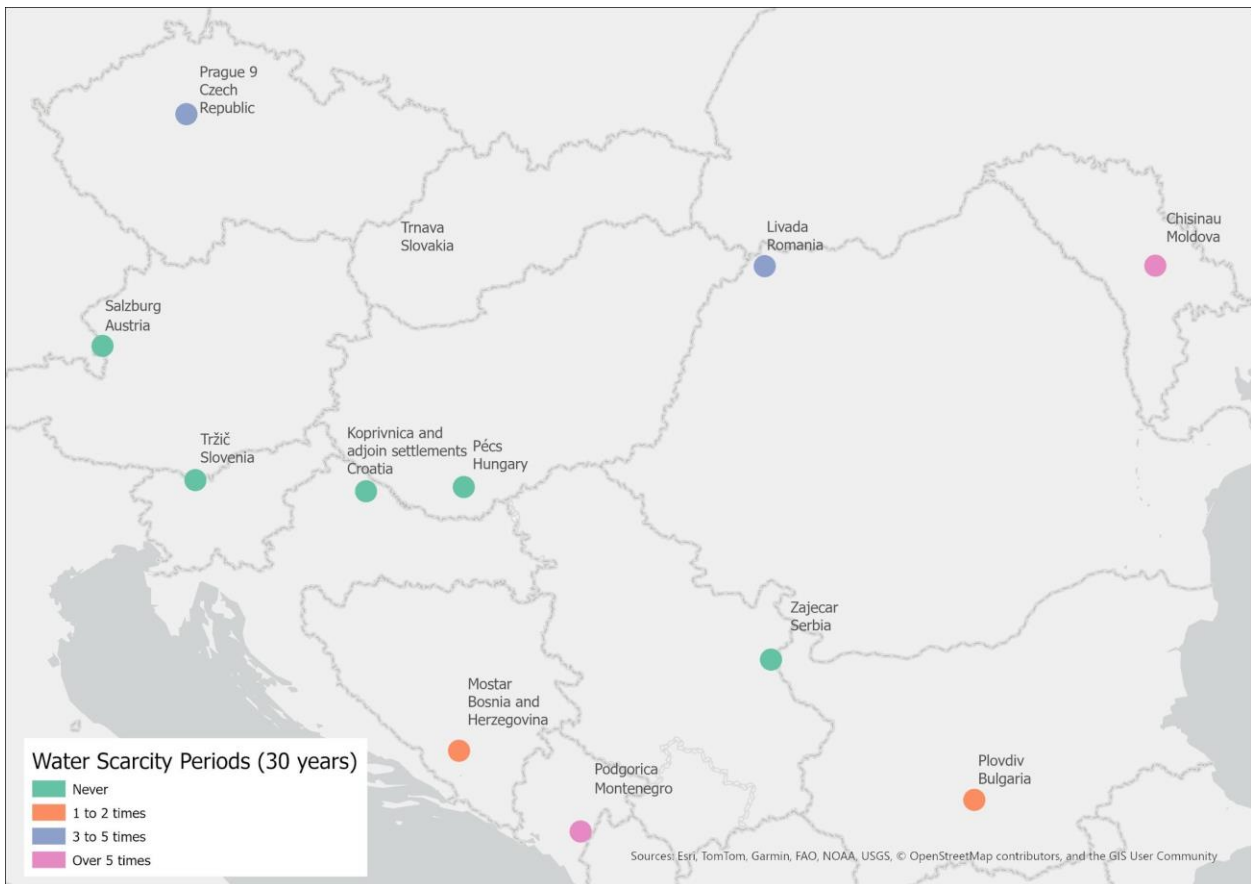


Figure 5: Water shortages

Listing 3: Water shortages

Water Scarcity Probabilities

High: Podgorica, Prague 9

Moderate: Tržič, Plovdiv, Livada, Chisinau, Mostar

Low: Pécs, Salzburg, Koprivnica and adjoin settlements

Non: Zajecar

No Data: Trnava

Water Scarcity Occurrences (30 yrs)

Over 5 periods: Podgorica, Chisinau

Between 3 and 5 periods: Livada, Prague 9

1 and 2 periods: Mostar, Plovdiv

Never: Zajecar, Tržič, Pécs, Koprivnica and adjoin settlements, Salzburg

No Data: Trnava

Drought Probabilities

Very High: Pécs

High: Prague 9, Plovdiv, Koprivnica and adjoin settlements, Podgorica, Tržič, Mostar, Zajecar

Moderate: Livada

Low: Chisinau, Salzburg

No Data: Trnava

3.4 Fire danger

Droughts combined with long heat waves can cause fire outbreaks. The expert knowledge for probability of fire danger of the pilot sites is shown in Figure 6. Fire danger is very high to high for Mostar, Podgorica and Zajecar (Listing 4). High fire danger corresponds to the high probability of droughts (Figure 6).

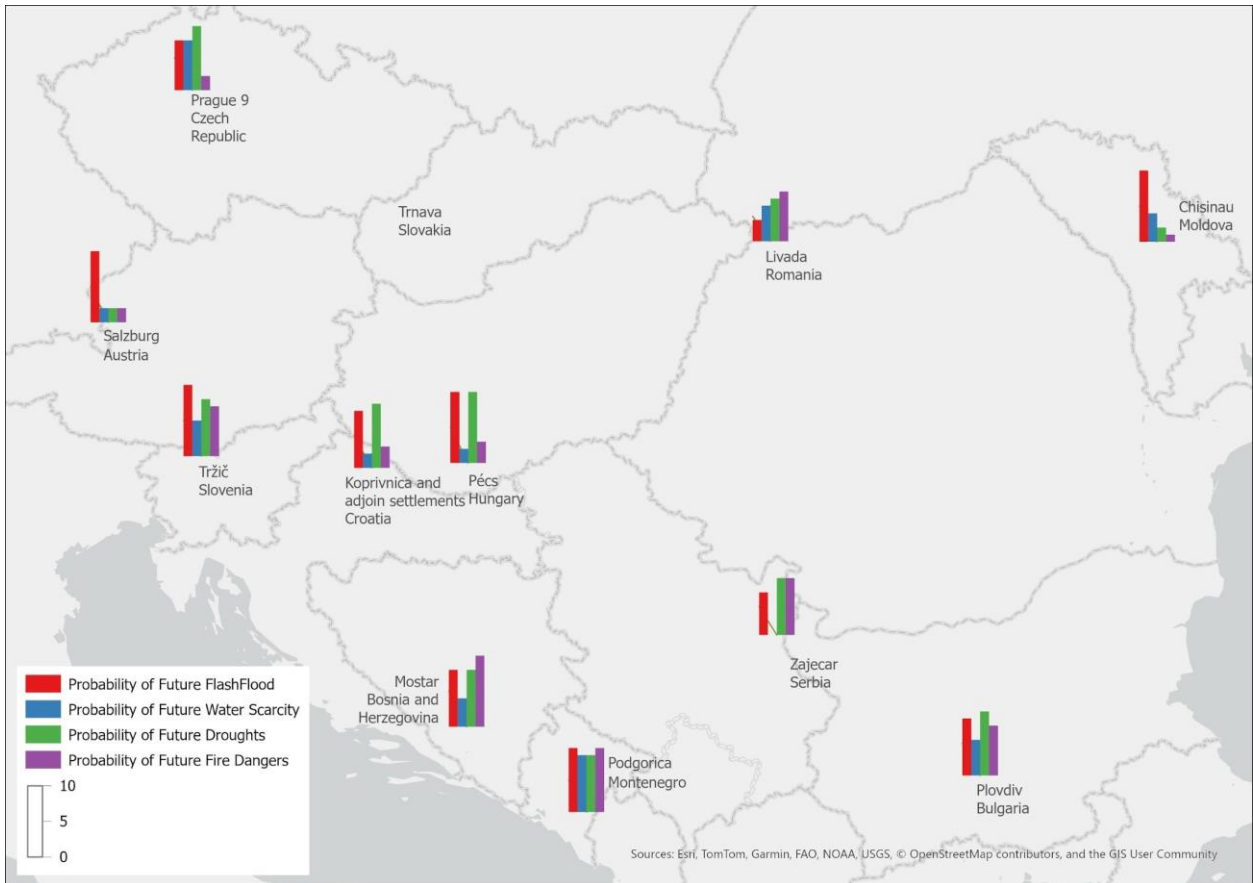


Figure 6: Fire danger

Listing 4: Fire danger

Fire Danger Probabilities

Very High: Mostar

High: Podgorica, Zajecar

Moderate: Plovdiv, Tržič, Livada

Low: Pécs, Koprivnica and adjoin settlements, Prague 9, Salzburg, Chisinau

No Data: Trnava

3.5 Underground conditions

Soils in various combination of clay, silt, and sand show different water infiltration, water storage, run-off, and underground water flows. According to the Food and Agriculture Organisation (FAO) classification of soils, different soil types are occurring in the pilot sites (Figure 7, Listing 5). Clayey soils, with less water infiltration and storage capacities, can be found in Podgorica and Zajecar. Sandy soils, with high drainage capacity occur in Mostar. Since Chisinau is a large city with a high rate of soil sealing the predominant soil type are technogenic.

The geologic underground provides an indication on water infiltration capacities and underground water flows. However, the geologic systems can be complex in a region. The geologic underground in the pilot sites varies (Figure 8). In most of the site's sediments are predominant. In Podgorica the underground is of siliceous rocks. A detailed description of the geological characteristics is prepared in (Listing 6).

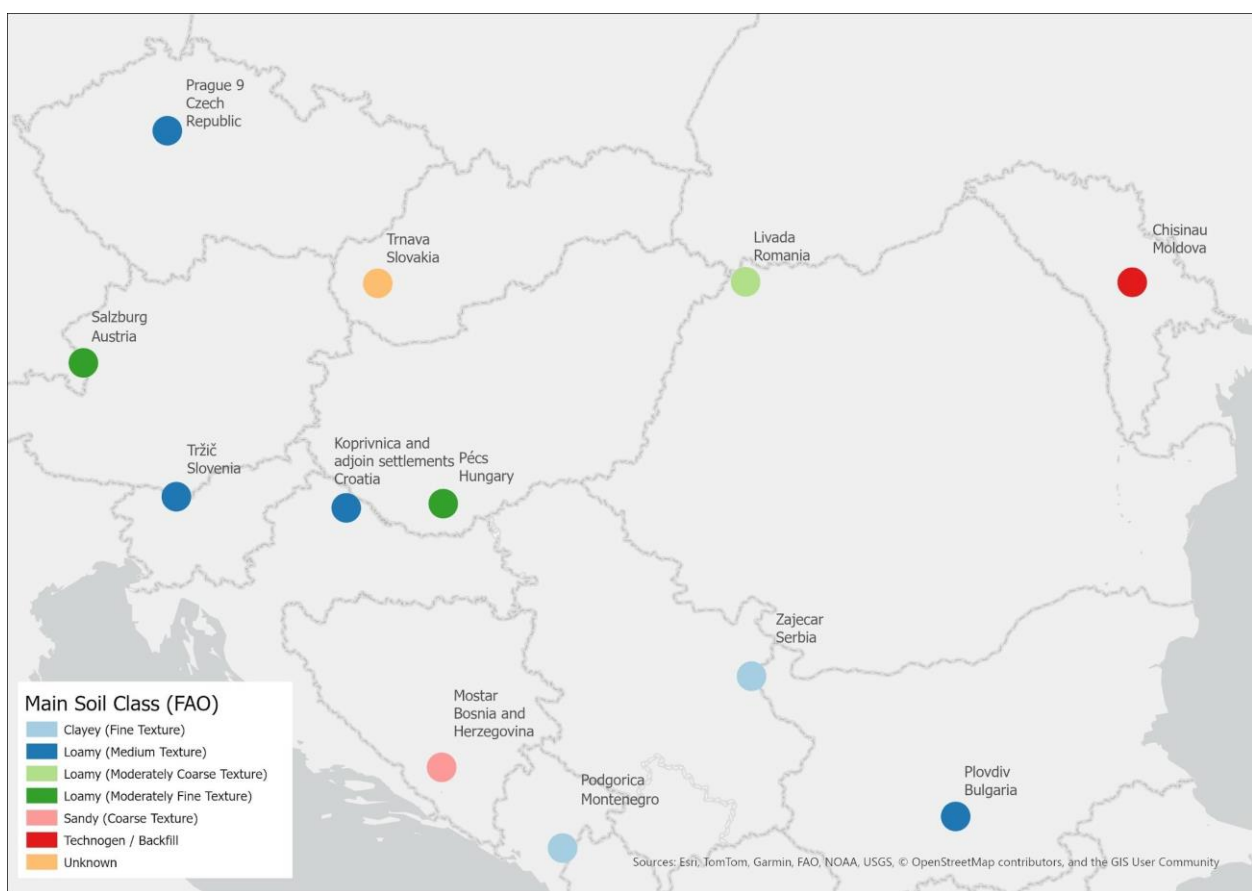


Figure 7: Soil types

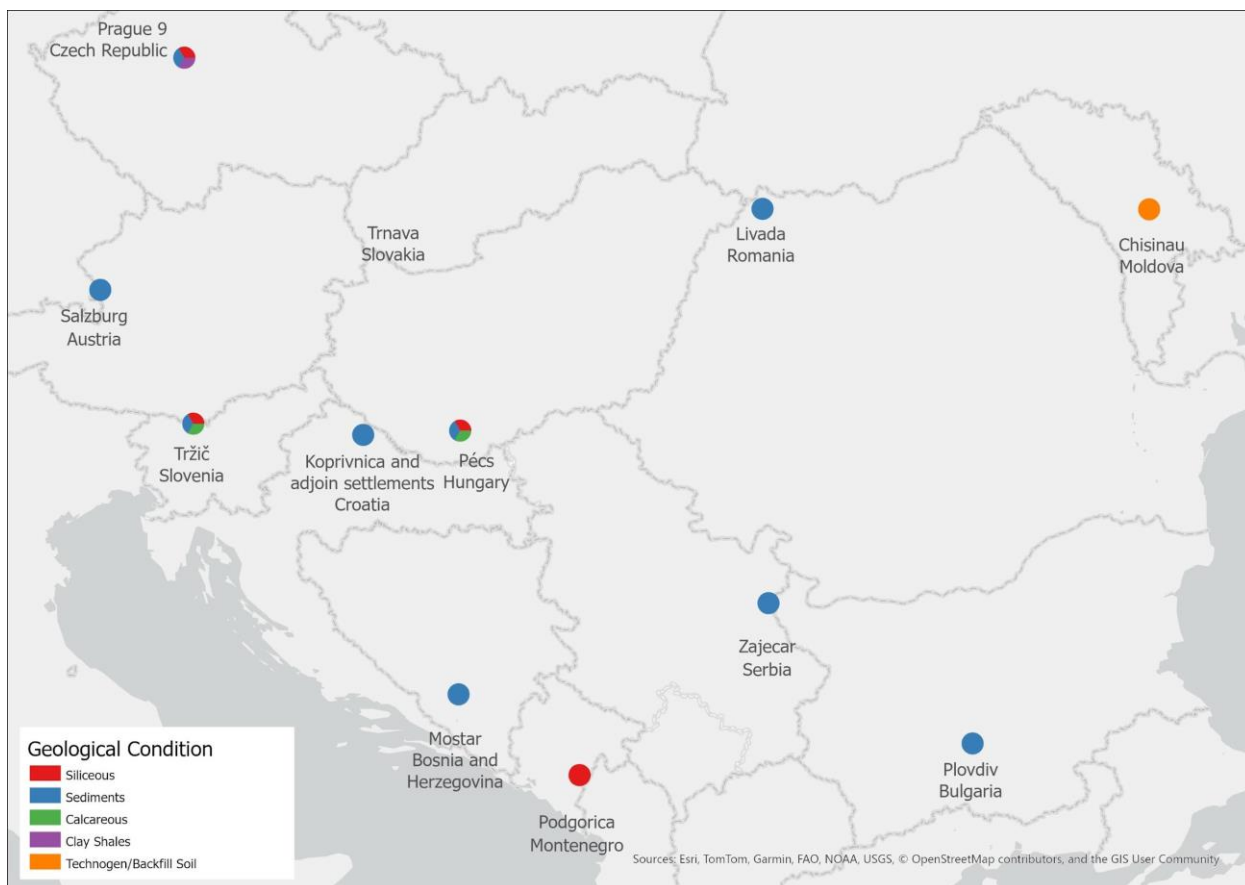


Figure 8: Underground conditions

Listing 5: Underground conditions

Main Soil Texture Class (FAO classification)

Clayey soils (Fine texture): Podgorica, Zajecar

Loamy soils (Medium texture): Plovdiv, Koprivnica and adjoin settlements, Prague 9

Loamy soils (Moderately coarse texture): Livada

Loamy soils (Moderately fine texture): Pécs, Salzburg

Sandy soils (Coarse texture): Mostar

Technogen soil/Backfill soil: Chisinau

No Data: Trnava

Unique entry: Tržič

Terrace - Rendzina (Loamy Sand or Sandy Loam)

Area between valley floor of Tržiška Bistrica and the terrace: Undeveloped riverine soils (Sandy Loam, Loamy Sand, or Silt Loam)

Answers possible: Sandy soils (Coarse texture), Loamy soils (Moderately coarse texture), Loamy soils (Medium texture), Loamy soils (Moderately fine texture), Clayey soils (Fine texture)

Geological Condition

Sediments: Zajecar, Livada, Koprivnica and adjoin settlements, Salzburg, Mostar

Siliceous: Podgorica

Siliceous, sediments, clay shales: Prague 9

Technogen soil/Backfill soil: Chisinau

Calcareous, Siliceous, Sediments: Pécs, Tržič

Unique Entry: Plovdiv (The water supply and sewage networks of Plovdiv are related only with the upper cretaceous and Neogene sediments, the Quaternary formations and cultural layer.)

No Data: Trnava

Listing 6: Geological Characterisation

Chisinau

Chisinau's geological characteristics are influenced by its location within the East European Platform (EEP), with its foundational structure—known as the Moldavian Platform in Moldova—extending from the Ukrainian shield. This platform is characterized by a gradual descent of about 10 meters over 1000 meters towards the southwest. The basement of the EEP is composed of consolidated Precambrian formations, such as Archean and Proterozoic rocks, with sedimentary layers in the central Moldavian Platform dating back to the Cenozoic, Mesozoic, and Paleozoic eras. Drilling data has confirmed the depth of these formations extends up to 2500 meters. Chisinau itself rests on sedimentary formations primarily of limestone, clay, sand, and loess. These soils, particularly the loess, contribute to the region's susceptibility to seismic activity, especially liquefaction during earthquakes. The city's seismic risk is heightened by its proximity to the Vrancea zone, one of the most active in Europe. In addition to seismic hazards, the region's fertile chernozem soils, while ideal for agriculture, are sensitive to erosion and compaction, especially in loess-based areas, complicating both agricultural and urban development.

Plovdiv

The morphological structure of the upper Thracian valley, in the western part of which is located Plovdiv, is developed on a tectonic depression, emerging as a graben, shaped under the major influence of Maritsa fault zone, which is dividing the Rhodopes from Sredna gora. The upper Thracian graben consists of Paleogene, Neogene and Quaternary sediments, which rest on rocky substrate with block structure. In the valley of Maritsa River, which coincides in territory with Maritsa fault zone, there are block structures of different size and type – grabens, horsts, uplifts, contraction faults, etc. Among them are the Plovdiv depression and the Plovdiv horst, represented by in-valley heights, known as the Plovdiv hills, genetically related with deep tectonic faults, conductors of volcanic activity. The following chronostratigraphic units have been established in the Plovdiv depression: pre-Cambrian, upper Cretaceous, Paleogene, Neogene and Quaternary.

Zajecar

Aluvion 0-10m, Neogenic Sediment 10-500m

Prague 9

Prague 9, like the rest of the city, is situated within the Bohemian Basin, which is a geological formation primarily composed of sedimentary rocks. Here are some key geological characteristics of Prague 9 and the surrounding area. Prague is located within the Bohemian Massif, a large and ancient geological formation in Central Europe. The massif consists of various types of rocks, including igneous, metamorphic, and sedimentary rocks, which were formed over hundreds of millions of years. Much of the bedrock underlying Prague and its surroundings consists of sedimentary rocks deposited over millions of years in ancient seas, lakes, and river systems. These sedimentary rocks include sandstones, shales, limestone, and marl. The Vltava River, which flows through Prague, has played a significant role in shaping the landscape and geology of the region. The river has cut through layers of sedimentary rocks, creating valleys, and exposing geological formations. In addition to the underlying bedrock, Prague 9 may also have Quaternary deposits such as alluvial deposits, glacial deposits, and loess. These deposits were formed during the Pleistocene Epoch and the Holocene Epoch and can influence soil composition and terrain features. While not as prevalent in Prague as in some other parts of the Czech Republic, karst landscapes characterized by limestone/karst formations, sinkholes, and caves can be found in areas surrounding the city. The Bohemian Basin has experienced tectonic activity throughout its geological history, including folding, faulting, and volcanic activity. Although the region is relatively stable today, evidence of past tectonic events can be seen in the geological structures and formations. These are just a few of the geological characteristics of Prague 9 and its surroundings. Detailed geological maps, studies, and surveys provide more comprehensive information about the specific rock types, structures, and geological history of the area.

Livada

Geological formations specific to the existing morphologies are intercepted, finding both sedimentary and magmatic formations. Over the crystalline foundation, the Tertiary seas deposited a series of sediments: clays, limestones, conglomerates, sandstones, marls, sands, in variable thicknesses from a few dozen to over 2,000 meters. Following the volcanic eruptions, Neogene sediments were deposited over

this Paleogene flysch

- Among the more common Neogene eruptive rocks are: rhyolites, andesites (basaltoid andesites are the most recent spread throughout the Oaş-Igriş-Gutâi chain), porphyritic granodiorites, porphyritic diorites and dacites

- Neogene sedimentary deposits are formed by clays, marly clays, sands and gravels.

Quaternary deposits, formed by loams, clays and clays brought from hilly regions, occupy the flat surfaces of the low piedmonts, terraces and plains; those formed from fluvial deposits and reworked sands occupy the young low deltaic plains (Ecedea), the meadows and the Nir Plain. In Satu Mare county, brown podzolic soils are found, predominant on the hills of the piedmont and in the lower

terraces of the watercourses, formed over, marls, sandstones, clays and sands. They have a low fertility, being used as land for agricultural crops, pastures, hayfields and plantations with fruit trees.

The relief of the plains is characterized by wide interfluvies, with smooth or slightly undulating shapes, within which alluvial or aeolian sedimentation has determined the formation of a diversity of soils (chernoziomic brown, forest brown, alluvial, alluvial brown, etc.), suitable for agricultural crops. The most extensive types of soil are brown luvimpermeable soil (1 8.4 %) and bed luvisol (1 3.3 %), followed by argiloiluvial brown soil (8.5 %), brown eumezobasic soil (1 1.0 %), pseudogleic (1 0.3 %), uvial argillaceous chernozem (8.5 %), cambium chernozem (6.4 %), alluvial soil (5.1 %), lacovishte (4.3 %), gleic soil (2, 5 %), acid brown (1.9 %), vertisol (1.8 %), solonets (I, I %), psammosol (I, O %). The other types of soils occupy surfaces of less than 1%.

From a hydrological point of view, the city of Livada is located in the hydrographic basin of the Tur River, which has as its tributary the Racta stream and the Egher stream, collectors of water from the component localities: Livada, Livada Mica, Dumbrova and Adrian.

As for the altitude, the mountain area varies between 900-1200 m. and at the Tisa confluence of the Tur river the altitude is 115 m. So the absolute drop is 875 m. The average altitude up to the village of Turulung 370 m. Albia lui it has a short length in the northern part of the town of Adrian, located on the border between Livada Town and Turulung Commune. The Racta stream, the main water collector in the studied area, flows into it. The Racta Stream has a length of approx. 6.7 km and is the hydrological collector that crosses the town of Livada through the center of the town, also collecting the surplus water from the locality of Livada Mica, the south-east of the locality of Dumbrova and the south-west of the locality of Adrian.

On these watercourses, the maximum flows are achieved in spring and early summer, periods when the maximum rainfall is also achieved. Minimum flows are achieved at the end of summer and at the beginning of autumn. The flooding phenomena are related to the torrential rains, when large accumulations of water occur in the characteristic flat areas of the city of Livada, or by flooding some riverbeds (Tur River).

From the standing water category, we can mention: the Adrian fishpond located in the east of Adrian locality and numerous ballast exploitations that create ponds and artificial lakes.

Koprivnica

In a structural sense the whole wider area of Podravina around the city of Koprivnica belongs to the structural unit of Drava River Basin where dominant role has the Legrad Threshold which is formed along the Ludbreg – Nagykanisza Fault. Together with the Drava Fault they represent the dominant structures in the study area. Both existing well fields, Ivanščak and Lipovec, are formed in Quaternary deposits but have very different hydraulic and spatial characteristics.

Pécs

Alluvial deposits at lower elevations, solid rocks, including sandstone and limestone at higher elevations, about above 150 m asl

Salzburg

Salzburg is located on the northern edge of the Austrian Alps. The mountains within the city, Gaisberg, Kühberg, Kapuzinerberg and Festungsberg are part of the Limestone Pre-Alps. The gently rolling hills to the north of the city belong to the flysch zone. The rock body is characterized by the alternation of clay stones and coarse-grained rocks (late and post-glacial lake clays and river gravel deposits). The Salzburg basin was formed between two ice ages. During the warm periods, the loose material was removed by glacier meltdown. In both the interglacial and postglacial periods, a lake around 30 km long and 15 km wide was formed in the basin, in which large banks (Kapuzinerberg, Mönchsberg, Rainberg, Hellbrunner Berg) were deposited. Near the Salzach, the Salzburg basin consists of a low-lying alluvial plain (alluvial soil formed on the banks of watercourses or by glaciers). Various terraces were created by the redistribution of the Salzach, with fresh soils and moorland.

Tržič

The northern part of the municipality Tržič is represented by glacial relief, which is typical for the high mountains of the Central Karavanke and the Lomščice valley with the northern slopes of Storžič. To the south, the Tržiška Bistrica valley is a destructive fluvial-sedimentary relief.

Northern part/high mountain part/ ridge of Košuta (2133 m asl) Triassic limestones and dolomites, dominated by karst hydrography.

Central part/ mountain belt (up to 1600 m a.s.l.) (extremely varied geological composition - sandstones, silicified feldspars, conglomerates, breccia, limestone, dolomite, etc.); a well-developed river network; watercourses have a pronounced torrential character.

The flatland along the Tržiška Bistrica and its tributaries - in the southern part of the municipality there is a glacial-river terrace of the Tržiška Bistrica; river and glacial alluvial deposits. The pilot area is located on a flat glacial-river terrace above the right bank of the Tržiška Bistrica. It extends from the valley bottom of the Tržiška Bistrica, across its terraces to the steep south-eastern slope of Dobrče (1634 m).

Mostar

The stratigraphic column of the region to which the studied location (Mostar valley) begins with limestone rocks of the Upper Cretaceous and Lower and Middle Eocene. They are bedded to thickly bedded, of excellent geomechanical characteristics with stable slopes formed at different gradients, even over 90 degrees. River terraces (fluvial conglomerates and breccias) are developed close to river flows in the form of thick beds. Processes of degradation and weathering are often visible in the overlying part of the beds, and fast transformation into cohesionless sandy-gravelly material in the underlying part. Groundwater is routed through these contact zones. As the river cuts its bed in fluvial conglomerates, the speed of water filtration in sides increases and loose material is washed out, creating the typical hollows. The formed underground voids cause the effect of cantilevers in river terraces, and they break off in the form of large blocks and fall into the riverbed. In view of their physical and mechanical, or engineering geological characteristics, these deposits range from gravels as cohesionless sediments to solid thick-bedded conglomerates characterized by high strength and compactness, and they behave as solid rock masses. Between these two extremes, there is a whole range of intermediate variations depending on cementation levels and thickness of conglomerates.

Podgorica

Terrain in Podgorica has a complex geological structure. The age of rock masses is younger Paleozoic, Mesozoic and Cenozoic, with lithological parts of mostly sedimentary rocks with a smaller part of metamorphosed rock masses. In terms of facies, they are specific for the southeastern Dinarides:

Clay-shale facies - stratified, shale, clayey-water-sandy layers with and without the lenses of conglomerates, breccias and layers of clayey, marly or sandy limestones of the younger Paleozoic and the oldest Mesozoic – Lower Triassic. The rock masses of this facies build only smaller parts of the terrain, Komovi mountain massif.

Carbonate facies - stratified, less often massive limestones, dolomitic limestones, limestone dolomites and dolomites, less often clayey, marly, or sandy triassic, Jurassic, Cretaceous and Paleogene. Mostly in the hilly and mountainous terrains.

Flysch facies consisting of clays, marls, sandstones, limestones, and transitional variants of these lithological members of the end of the Mesozoic and the beginning of the Cenozoic (Durmitor flysch, K2Pc) that build the far northeastern parts of the basin. There is also Eocene flysch (E) made of clays, marls, sandstones and transitional varieties of these elements both with and without layers of breccias and conglomerates.

Classical facies made of quaternary sediments: glacial (sand, gravel and larger semi-rounded blocks with a very variable granulometric composition); glaciofluvial (sand, gravel and larger pebbles, in the largest part of the Zeta plain), glaciolimic (clay, clayey and dusty sands and fine-grained sands); deluvial (unrounded sand, gravel and larger blocks, granular sediments are sometimes mixed with various clays and humus in surface zones, alluvial (rounded sand, gravel and waves, and regularly occur in the riverbeds).

The terrains mostly belong to the regional geotectonic unit of the first order called the zone of the High Karst, and a very small part (the area of Komovi), to the regional geotectonic unit of the first order called the Durmitor Cover. The zone of the High Karst is with numerous reverse fractures and fractures in general – faults and numerous fold structures. These scales of the High Karst zone are with distinct anticlinorium and synclinorium. Anticlinorium are made by older Mesozoic carbonate sediments, and synclinorium by younger carbonate sediments and Cretaceous-Paleocene and Eocene sediments. The elements providing fracture and fold structures with spatial deposition of layers are Dinaric, i.e. from northwest to southeast all the way to the terrain west of Podgorica. The terrains of Podgorica belong to that part of the Dinarides. Carstification in spacious and powerful carbonate rock masses has left numerous and diverse surface and underground phenomena characteristic of the Holokarst. Aeolian erosion has left loess deposits on the edges of the hills that protrude above the level of the Zeta plain, on the plain itself and among the glaciofluvial sediments of the plain. Fluvial erosion gave deep canyons and relatively extended valleys. Glacial erosion on high mountains left grainy sediments of very variable granulation (frontal, lateral and floor) moraines and smaller glacial lakes. Lake erosion has left traces along the perimeter of the glacial lakes, and lake clays and peat are present. Crack-cavernous porosity is the main feature of the rock masses. Atmospheric deposits plunge where they fall feeding into the underground light karst shattered groundwaters emptied along and around the perimeter of erosion bases through permanent and occasional springs, estavelles and hot springs. The terrains are hydrogeological collectors, as well as reservoirs. The watershed is underground and often zonal. The velocities of groundwater movement range from 1 to 11 cm/s. Summarized, the intergranular rock masses of the Zeta Plain are with a filtration coefficient of $K_f = 1 \times 10^{-1}$ to 1×10^{-3} cm/s.

3.6 Topographical Characteristics

This subset of geographical studies focuses on the shape and slope of land surface, its organisation, and structures and gradients. Topographical features are generally described in

terms of their elevation, orientation, and spatial distribution. In SpongeCity the focus is on indicators for drainage patterns. Figure 9 and Listing 7 show the topographical characteristics of the pilot sites. Valleys and basins accumulate a lot of water from the surroundings, but show a high water discharge the higher the elevation difference is (Figure 10). Flat areas combined with specific underground conditions (e.g. clayey soils) are more affected by flash floods, since the water infiltration and water discharge are much slower.

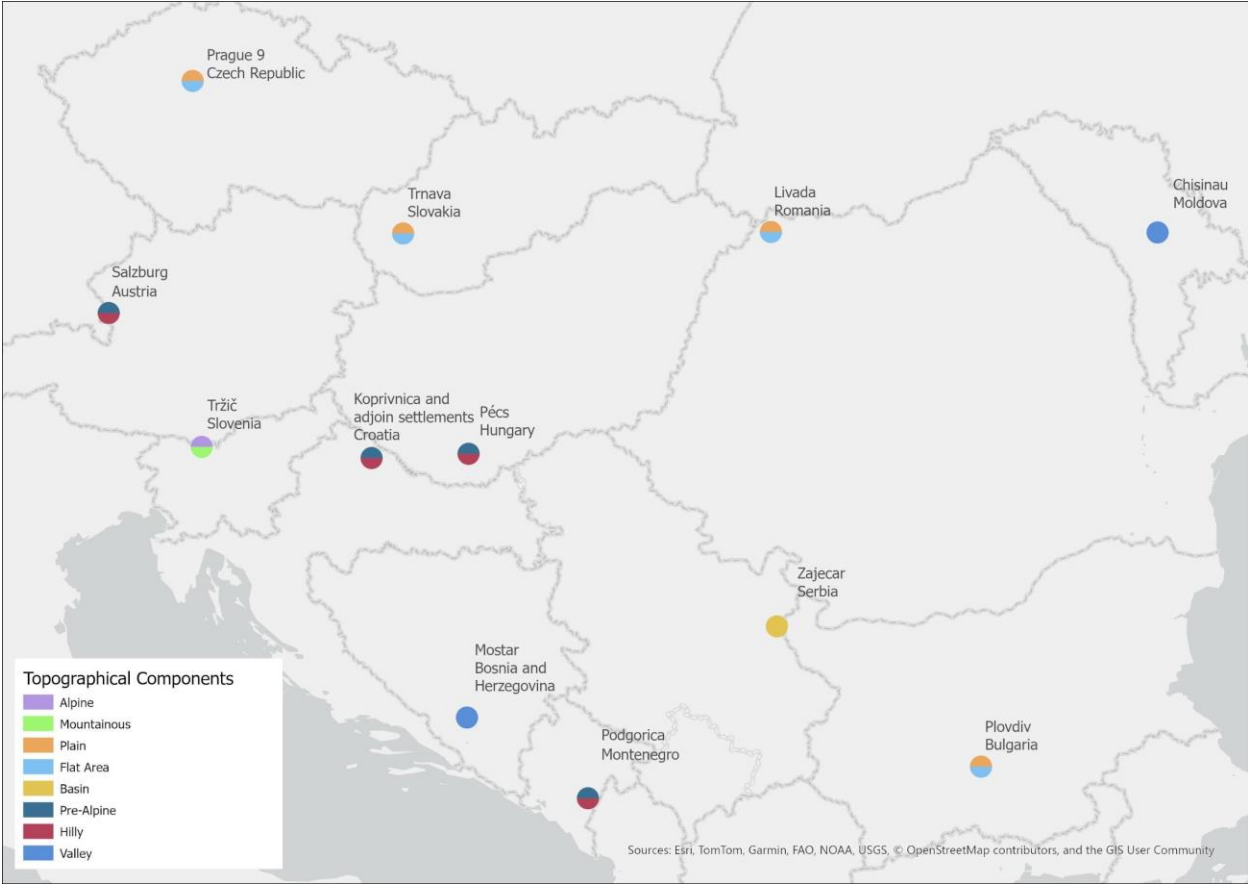


Figure 9: Topographical characterisation

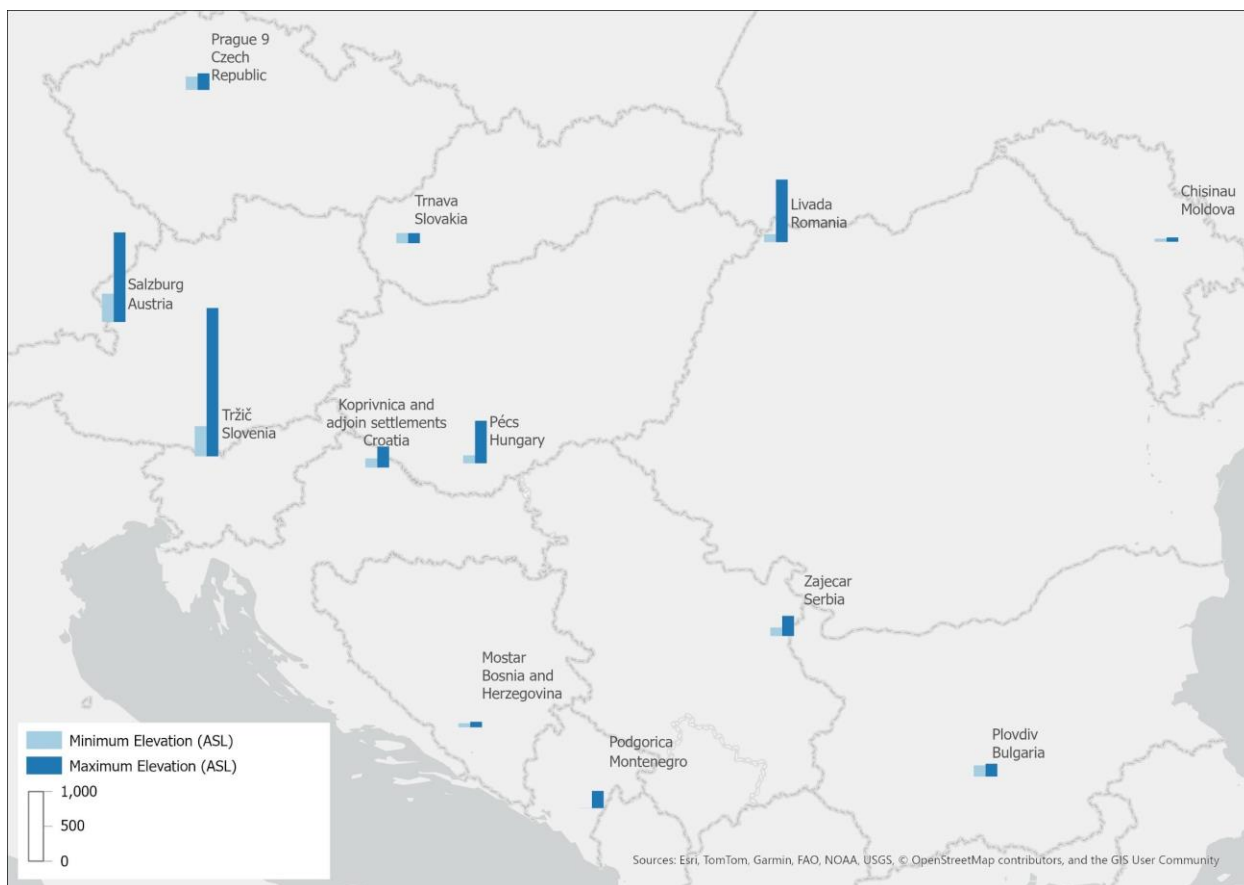


Figure 10: Minimum and maximum elevation indicating elevation difference

Listing 7: Topographical Characteristics

Topographical Characterisation

Basin: Zajecar

Plain / Flat Area: Plovdiv, Livada, Prague 9

Pre-Alpine / Hilly: Pécs, Salzburg, Koprivnica, Podgorica

Valley: Mostar, Chisinau

Mountaineous: Tržič

No Data: Trnava

Elevation Difference (Min – Max ASL)

Small: Trnava, Chisinau, Mostar, Plovdiv, Prague 9

Medium: Koprivnica and adjoin settlements, Zajecar, Podgorica

High: Pécs, Livada

Very high: Salzburg, Tržič

Pilot Site Total Area (sq-km)

0 – 50: Zajecar, Mostar, Prague 9

50 – 100: Plovdiv, Koprivnica and adjoin settlements, Trnava, Salzburg

100 – 150: Livada, Plovdiv, Chisinau, Podgorica

150 – 200: Pécs, Tržič

Amount of Sealed Surfaces (%) Compared Pilot Site Total Area

0 to 20 percents: Tržič, Livada

20 to 40 percents: Prague 9, Koprivnica and adjoin settlements, Salzburg, Pécs

Unknown: Mostar, Podgorica, Zajecar, Plovdiv, Chisinau, Trnava

3.7 Population characteristics

The population size of a region is important to assess how many people are affected in case of natural hazards like floods, droughts, water scarcity, and wildfires. The number of inhabitants is important for spatial planning and measurement actions. The population density, inhabitants within a region, indicate for space requirements for living, infrastructure, and recreation. The population density indirectly indicates on the sealing of surfaces within an area. However, it is limited by the definition of the administrative boundaries. The more rural surroundings of a settlement are included, the lower the population density and reliability of the indicator. Similar for the sealing rate, it varies by the definition of the administrative boundaries. A spatial explicit sealing rate of sub-regions of pilot sites is important for spatial planning and measurement actions, like the implementation of sponge city concepts.

Very large and large cities by population are Chisinau, Plovdiv, Podgorica, Salzburg, Pécs (Figure 11, Listing 8). The smallest pilot sites are Tržič and Livada. Urban, with a high population density are Prague 9, Chisinau, Salzburg, Plovdiv, and Mostar. The sealing rate is known for the cities Prague 9, Salzburg, Tržič, Koprivnica, Pécs and Livada (Figure 12).

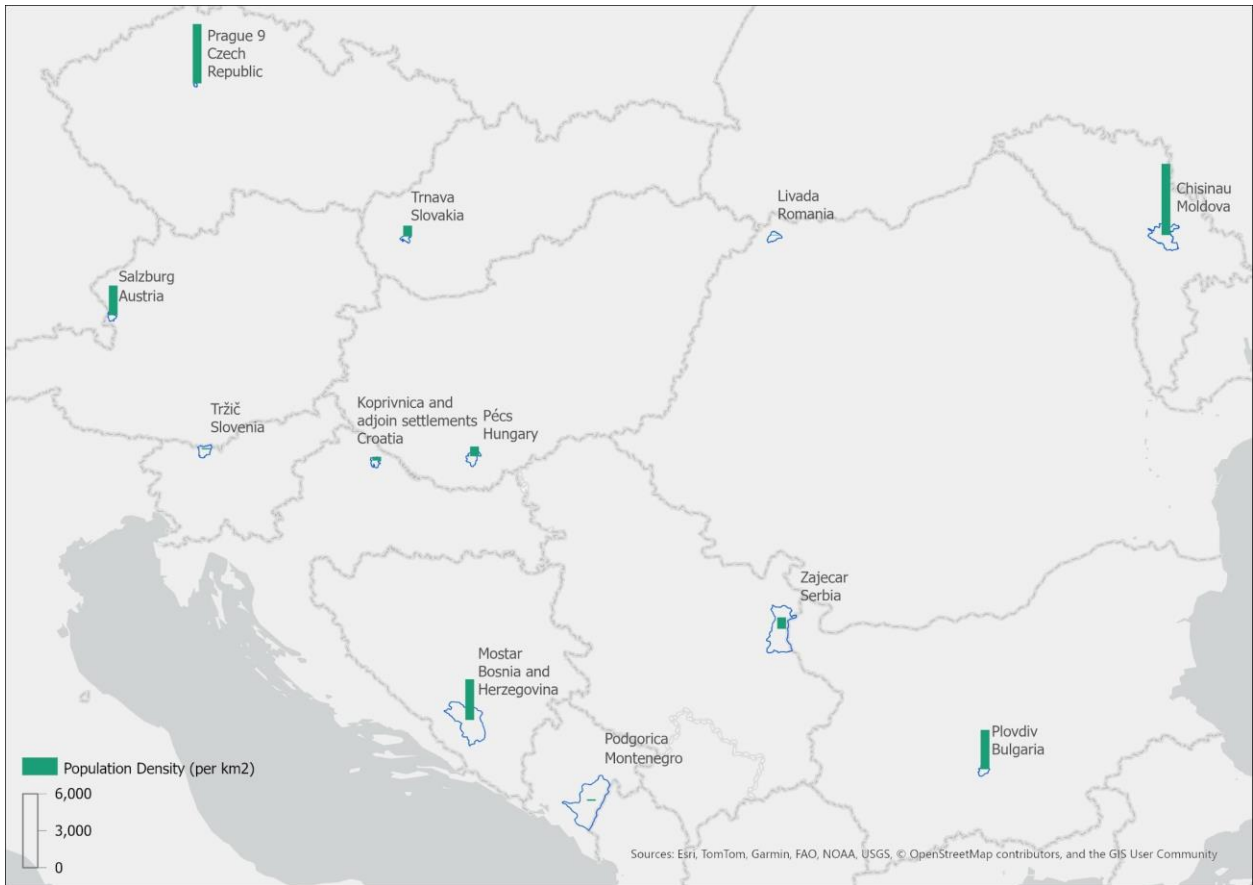
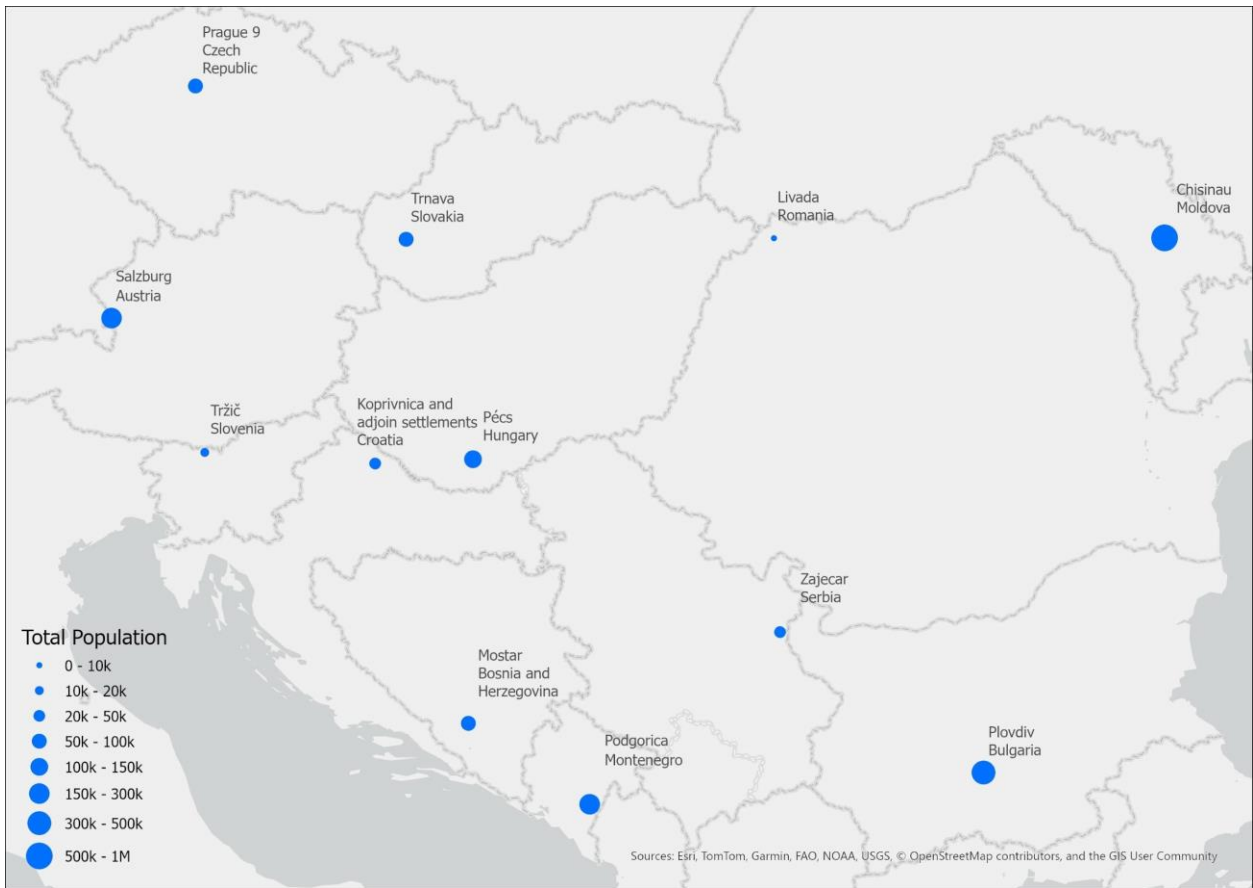


Figure 11: Population characteristics

Listing 8: Population characteristics

Population

Very Large: Chisinau

Large: Plovdiv, Podgorica, Salzburg, Pécs

Medium: Prague 9, Trnava, Mostar, Zajecar, Koprivnica and adjoin settlements

Small: Tržič, Livada

Population Density (per km²)

Very High: Prague 9, Chisinau

High: Salzburg, Plovdiv, Mostar

Moderate: Pécs, Trnava, Zajecar

Low: Livada, Tržič, Podgorica, Koprivnica and adjoin settlements

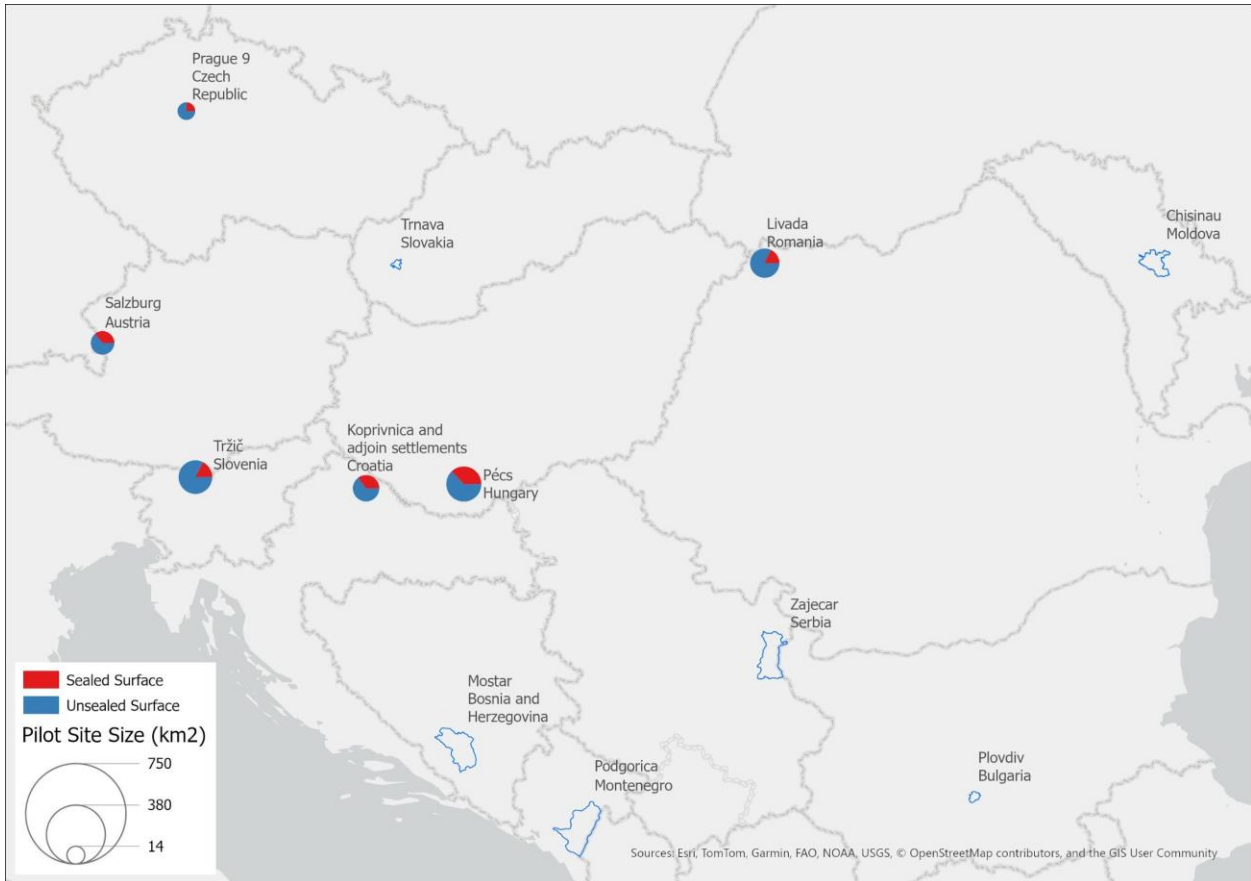


Figure 12: Ratio of sealed to unsealed surfaces

3.8 Visible comparison

The publicly available PSPT (<https://tinyurl.com/SpongeCityPilotMap>, Figure 13) has been used by partners in period 2 (Figure 14, Figure 15). Location aware pictures on sponge city related features and properties are taken for each pilot site. Included is a brief explanation of what is visible from the picture. In general, the pilot sites are differently prepared to mitigate natural hazards. The picture documentation helps to understand issues in pilot sites and to consider those for the SpongeCity toolbox conceptualisation.

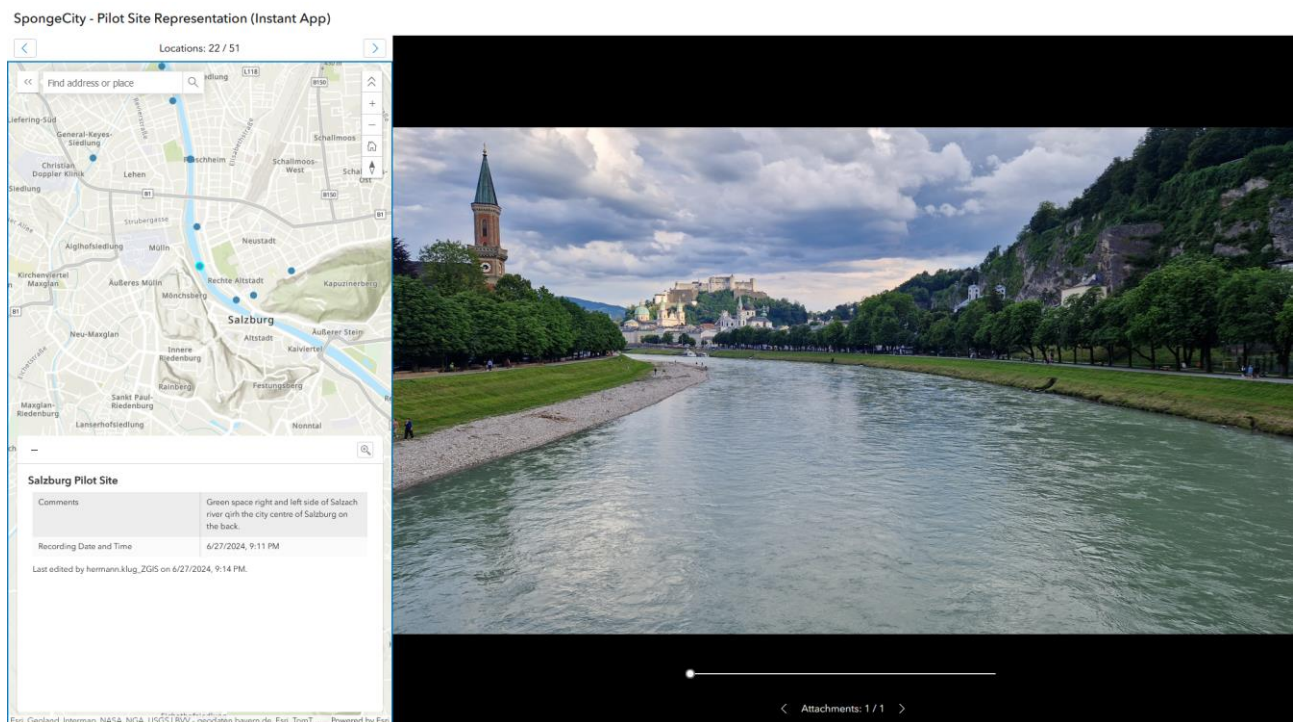


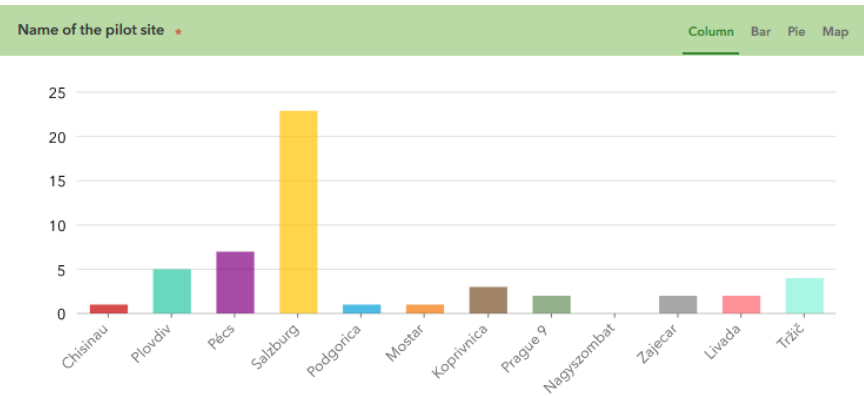
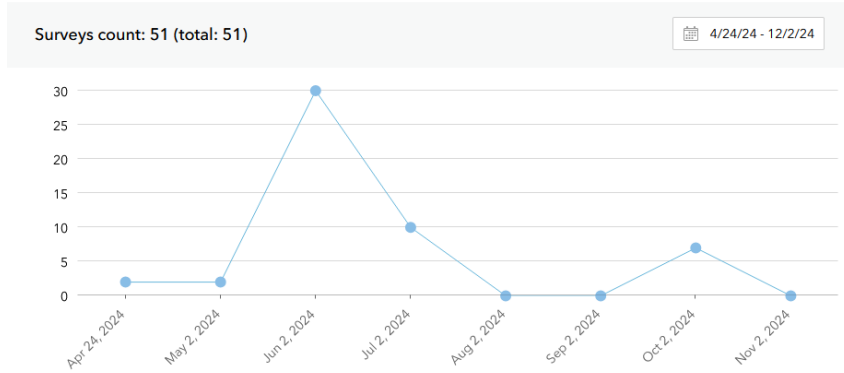
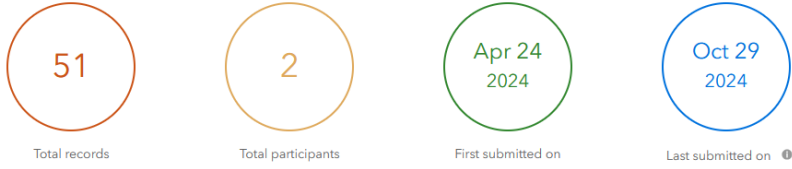
Figure 13: Example entry from Salzburg, Austria

SpongeCity - Pilot Site Representati... Overview Design Collaborate Analyze Data Settings

This survey is designed to enable taking and visualising pictures within the SpongeCity pilot sites. An online map will automatically capture all picture from all twelve pilot site and provide an overview of the conditions across the Danube River Basin.

Owner: hermann.klug_ZGIS, created: Apr 17, 2024, updated: Apr 24, 2024

This survey is shared with Everyone (public) and PLUS Geoinformatics Salzburg



Hide table

Empty categories Sort

Answers	Count	Percentage
Chisinau	1	1.96%
Plovdiv	5	9.8%
Pécs	7	13.73%
Salzburg	23	45.1%
Podgorica	1	1.96%
Mostar	1	1.96%
Koprivnica	3	5.88%
Prague 9	2	3.92%
Nagyszombat	0	0%
Zajecar	2	3.92%
Livada	2	3.92%
Tržič	4	7.84%

Answered: 51 Skipped: 0

Figure 14: PSPT Usage statistics



Images: 51



Figure 15: PSPT pictures and credits

4 Discussion

The large size of a few pilot sites is limiting since most of the territory is rural. At the same time, rural areas are important for upslope and/or downslope water retention of an agglomeration. The rural areas with specific ecosystem services, like water retention, support in protecting urban areas. Therefore, taking on a holistic perspective of processes and functions working in cities, the interaction with the "hinterland" must be included. Considering the development of the SpongeCity toolbox (<http://spongecity.sen2cube.at/>) for analysing potential adaptation measures to increase water retention and storage opportunities, the size of an area is neither limiting the analysis nor it is increasing the efforts. The Sentinel-2 satellite scenes will be automatically downloaded and processed.

The mentioned processes and functions in urban areas are scale dependent. While we are considering hydrological retention areas, these could be large forests or basins, at the same time smaller parks, single trees, or green roof tops. The same is true for the hydrological infrastructure. This could be either a big stream (Salzach, Danube) or smaller ditches and pipes of a connecting sewage system. Meteorological phenomena usually cover small scale areas (large extend) while the local situation (sealed surface, steep slope, confluence of streams) is causing a flash flood or shortage of water on large scale.

While discussing the pros and cons of a size of a pilot site from environmental perspective, an administrative perspective is also important. Boundaries of municipalities define the responsibilities for spatial planning including adaptation and mitigation action. These must consider build up land but also need to consider the surrounding landscape. Thus, there are political reasons to account for a certain area. Additionally, these districts are subject for statistics. Statistics provide additional numbers for, e.g., to prevent population and infrastructure from damage.

In terms of total area, the sites range from small, compact regions to expansive territories. Zajecar, Mostar, and Prague 9 represent the smallest sites, each covering less than 50 square kilometres. These compact areas are likely to exhibit concentrated development or high population densities. Moderate-sized areas, spanning 50 to 100 square kilometres, include Plovdiv, Koprivnica and adjoining settlements, Trnava, and Salzburg, offering balanced space for mixed urban and suburban land use. Larger areas, such as Livada, Plovdiv, and Chisinau, cover 100 to 150 square kilometres, allowing for greater spatial flexibility. Notably, Pécs and Tržič (settlement and surrounding), with areas between 150 and 200 square kilometres, are among the largest pilot sites in this category. The proportion of sealed surfaces varies considerably among the pilot sites. Tržič and Livada have the lowest percentages of sealed surfaces, between 0 % and 20 %, suggesting lower levels of urbanization and a prevalence of green or open spaces. Moderate levels of urbanization, with sealed surfaces between 20 % and 40 %, characterize Prague 9, Koprivnica and adjoining settlements, Salzburg, and Pécs, indicating balanced land use. However, data on sealed surfaces are unavailable for Mostar, Podgorica, Zajecar, Plovdiv, Chisinau, and Trnava, emphasizing the need for assessing the degree of urbanization and land cover with spatial explicit information in these areas. Smaller populations are found in Tržič and Livada, likely aligning with their limited urban development and lower sealed surface percentages. Medium population sizes characterize Prague 9, Trnava, Mostar, Zajecar, and Koprivnica and adjoining settlements, balancing urban and semi-urban characteristics. Larger populations are observed in Plovdiv, Podgorica, Salzburg, and Pécs, reflecting their status as significant urban centres with higher infrastructure demands. Chisinau, with its very large population, stands out as a major urban hub requiring comprehensive resource management and urban planning strategies. Population density

varies across the pilot sites, underscoring differing levels of urban compactness. Livada, Tržič, Podgorica, and Koprivnica and adjoining settlements exhibit low population densities, likely providing adequate green spaces. Moderate population densities characterize Pécs, Trnava, and Zajecar, blending urban and suburban lifestyles. High population densities are observed in Salzburg, Plovdiv, and Mostar, suggesting intensive land use and urbanized conditions. The highest population densities are found in Prague 9 and Chisinau, emphasizing the need for efficient resource management, infrastructure optimization.

High population density and extensive sealed surfaces, such as those in Prague 9, Chisinau, Salzburg, and Plovdiv, increase the susceptibility to flash floods. These conditions exacerbate surface runoff during heavy rainfall events, as impervious surfaces limit natural water infiltration. Sites like Mostar and Koprivnica and adjoining settlements, despite having medium populations, are also susceptible due to a mix of moderate sealed surface percentages and surrounding geographic features such as valleys. Conversely, low-density, and low-sealed areas like Tržič and Livada are less vulnerable, as they retain more natural infiltration capacity, reducing runoff and the likelihood of flash floods.

In the pilot sites Chisinau and Plovdiv are low annual precipitations (0 – 500 mm/year). This increases their vulnerability to droughts and water scarcity. Salzburg, Tržič, Mostar, and Podgorica have high annual precipitations (1000 – 1500 mm/year). This reduces risks for droughts and increases their susceptibility to flash flooding. Areas with moderate precipitation, including Zajecar, Prague 9, Pécs, and Koprivnica, often face seasonal challenges balancing water supply and demand, further challenged by fluctuating rainfall periods. Regions such as Trnava, Salzburg, and Chisinau have experienced intense rainfall during specific periods, with sites like Koprivnica and Tržič showing recent spikes in heavy precipitation. These patterns align with flash flood occurrences, which are frequent in Mostar, Podgorica, Plovdiv, Pécs, and Chisinau. Livada was never affected by flash floods and heavy rainfalls. Local experts rate a low probability for future flash floods. The probabilities of future flash floods are highest in Salzburg, Tržič, Chisinau, and Pécs, likely due to their combination of rainfall intensity, terrain, and drainage limitations, while sites such as Livada and Prague 9 face moderate to low risk. Chronic shortages in Podgorica and Chisinau, which have experienced over five scarcity periods in three decades, underline the need for an improvement of the water resource management. Moderate risk is observed in areas like Livada, Plovdiv, and Mostar. Meanwhile, sites such as Zajecar, Tržič, and Salzburg show strong resilience with no recorded water scarcity periods. Despite this, drought probabilities remain high for several regions, including Pécs, Prague 9, Podgorica, and Mostar, suggesting that even areas with sufficient rainfall are not immune to water shortages. High-risk areas such as Chisinau, Podgorica, and Plovdiv would benefit from enhanced infrastructure to manage flash floods and mitigate water scarcity. Conversely, stable regions like Livada and Zajecar could serve as models for sustainable water management.

The soil texture and geological conditions across the pilot sites reveal diverse environments that influence water infiltration, agricultural potential, and vulnerability to hydrological challenges. Soil texture varies from coarse sandy soils to fine clayey soils, each with distinct hydrological characteristics. For instance, Podgorica and Zajecar, characterized by clayey soils with fine textures, are likely to experience reduced infiltration and increased surface runoff, which could exacerbate flooding risks during intense rainfall. In contrast, sandy soils in Mostar, with their coarse texture, enhance infiltration but can contribute to groundwater vulnerability during drought periods. Sites with loamy soils of varying coarseness and fineness, such as Plovdiv, Pécs, Salzburg, and Prague 9, present a balanced profile with moderate infiltration and water retention capacity, supporting both agricultural and urban

requirements. Tržič presents a unique case with a combination of terrace soils, rendzina (loamy sand or sandy loam), and undeveloped riverine soils along the valley floor. These features suggest a mix of moderate permeability in the terrace and higher infiltration rates in sandy and loamy soils along riverine areas, influencing local hydrology. Chisinau, with its technogenic and backfill soils, highlights anthropogenic impacts, which may restrict natural infiltration and necessitate engineered drainage solutions. Meanwhile, Livada's moderately coarse loamy soils provide resilience to both drought and flooding through their balanced hydrological properties. The absence of detailed soil data for Trnava limits precise characterization.

Geologically, most sites exhibit sedimentary conditions, contributing to varied permeability and subsurface water storage. Zajecar, Livada, and Salzburg, with sedimentary profiles, are likely to have diverse infiltration rates depending on sediment composition. Podgorica stands out with siliceous geology, which tends to be less permeable, while Prague 9 features a mix of siliceous, sediments, and clay shales, challenging its groundwater dynamics. Pécs and Tržič, with calcareous, siliceous, and sedimentary elements, reflect complex geologies that affect both water flow and retention. Plovdiv's unique association with upper Cretaceous and Neogene sediments, combined with cultural layers, highlights the interplay of natural and anthropogenic factors in its geological framework. Chisinau's reliance on technogenic soils underscores human modification, impacting its hydrological response. Trnava lacks sufficient geological data for an in-depth analysis.

The topographical and elevation characteristics significantly shape the environmental and hydrological behaviour of the pilot sites. Zajecar's basin topology suggests potential susceptibility to water pooling and limited natural drainage, intensifying flood risks. In contrast, flat plains in Plovdiv, Livada, Trnava, and Prague 9 promote surface runoff but also allow for easier urban planning and infrastructure development. Tržič, situated in valleys surrounded by mountains, show complex hydrological dynamics, with runoff from surrounding slopes affecting valley-floor conditions. Pre-alpine and hilly topographies in Pécs, Koprivnica and adjoin settlements, Podgorica, and Salzburg create gradients that facilitates runoff, which may pose flood risks in lower-lying areas but also provide opportunities for gravity-fed drainage systems. The valley regions of Mostar and Chisinau could face potential waterlogging and sediment deposition. Elevation ranges further highlight site-specific characteristics. Sites with small elevation ranges, such as Trnava, Chisinau, Mostar, Plovdiv, and Prague 9, are relatively homogenous in terms of topography, simplifying hydrological modelling but increasing the risk of widespread impact during extreme weather events. Medium elevation ranges in Koprivnica, Zajecar, and Podgorica introduce moderate variability in water flow patterns. Large elevation ranges in Pécs and Livada and very large ranges in Salzburg and Tržič reflect more dramatic topographical changes, which could lead to localized hydrological variability, with areas of concentrated runoff and potential erosion in steeper regions.

The interplay of soil texture, geological conditions, topography, and elevation across these pilot sites underscores their diverse hydrological behaviours and susceptibilities. Clayey soils, flat plains, and small elevation ranges, as seen in Zajecar, align with high runoff potential and flooding risks. Conversely, sandy and loamy soils, combined with larger elevation ranges, as in Tržič and Salzburg, enable better drainage and infiltration but may pose erosion risks. Technogenic soils in Chisinau and anthropogenically influenced geology in Plovdiv necessitate tailored engineering approaches to address altered natural hydrological cycles.

The PSPT enabled another comparable view across different locations in the DRB. While some cities like Tržič and Pecs have partly very narrow surface sealed roads in steep slopes with

quick surface runoff other cities like Plovdiv, Zajecar and Salzburg provide retention basins and de-sealed surfaces for higher level of water infiltration.

5 Conclusion and Outlook

Within the SpongeCity project, twelve pilot sites were analysed according to their geographical characteristics. The locations show different topography, climatic and underground conditions. The pilot sites vary in size, population and sealing rate. That causes user needs on different spatial-temporal scales, which will be used for conceptualising the SpongeCity toolbox. Climate conditions will change in the future and demands for measurements to locally mitigate or adapt against natural hazards like flash floods, water scarcity, droughts, and wildfires. Within the last decades the urban agglomerations developed into more surface sealed areas. An increasing number of people are living in agglomerations, while extreme weather situations became more frequent and caused natural disasters. The SpongeCity toolbox will provide spatial-temporal information for the use in spatial planning and decision support. The offered data will help in the understanding of spatial-temporal phenomena and serves as a basis for conceptualising measurements for natural hazard mitigation and adaptation.

From discussing the size and the local distribution of the pilot sites we learned that different spatial-temporal scales have their value of interest. Having defined a large area does not necessarily mean, always being required to take on action on the whole area. Depending on the question of interest, internal city processes should be put in relation to outer urban areas. During the past decade climate change became a pressing issue for urban areas. Urban agglomerations developed into more surface sealed areas. An increasing number of people are living in agglomerations. Extreme weather situations became more frequent and caused flash floods and water scarcity and/or droughts. One future objective in relation to the SpongeCity Toolbox is to discover the rate and direction of change of the pilot sites since 2015 (launch of Sentinel 2). Of particular interest are for instance the increase of surface sealed areas, the reduction of green space and the spatial-temporal developments of surface waterbodies. Since there might be additional analysis options coming from stakeholders, a demand assessment is required to look for spatial-temporal improvements, mitigation, and adaptation actions. The lessons learned from this comparative pilot site study (deliverable 1.2.2) will lead to demand driven actions to be reflected in the pilot site toolbox using the Sen2Cube approach in the third Reporting Period.

❖ Literature

- BECK, H. E., T. R. MCVICAR, N. VERGOPOLAN, A. BERG, N. J. LUTSKO, A. DUFOUR, Z. ZENG, X. JIANG, A. I. J. M. VAN DIJK & D. G. MIRALLES (2023), High-resolution (1 km) Köppen-Geiger maps for 1901–2099 based on constrained CMIP6 projections. *Scientific Data* Nr. 10(1), p. 724, [10.1038/s41597-023-02549-6](https://doi.org/10.1038/s41597-023-02549-6).
- BLÖSCHL, G., C. RESZLER & J. KOMMA (2008), A spatially distributed flash flood forecasting model. *Environmental Modelling & Software* Nr. 23(4), p. 464-478, <http://dx.doi.org/10.1016/j.envsoft.2007.06.010>.
- CHENG, H., S. KIM, J. H. HYUN, J. CHOI, Y. CHO & C. PARK (2024), A multi-objective spatial optimization of wetland for Sponge City in the plain, China. *Ecological Engineering* Nr. 198, p. 107147, <https://doi.org/10.1016/j.ecoleng.2023.107147>.
- COUNCIL OF THE EUROPEAN UNION, D.-G. F. C. A. (1991), Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment. <http://data.europa.eu/eli/dir/1991/271/oj>.
- COUNCIL OF THE EUROPEAN UNION, D.-G. F. C. A. (1992), Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. p. 44, <http://data.europa.eu/eli/dir/1992/43/oj>.
- CZIGÁNY, S., E. PIRKHOFFER & I. GERESDI (2010a), Impact of extreme rainfall and soil moisture on flash flood generation. *Quarterly Journal of the Hungarian Meteorological Service* Nr. 114(1–2), p. 79–100.
- CZIGÁNY, S., E. PIRKHOFFER, L. NAGYVÁRADI, A. SZEBÉNYI, P. VASS & I. GERESDI (2010b), Potential areas of flood impoundment in human environments, Bükkösd Valley, SW Hungary. *Géomorphologie : relief, processus, environnement* Nr. 3, p. 301-310, <http://dx.doi.org/10.4000/geomorphologie.8007>.
- CZIGÁNY, S., E. PIRKHOFFER, L. NAGYVÁRADI, P. HEGEDŰS & I. GERESDI (2011), Rapid screening of flash flood-affected watersheds in Hungary. *Zeitschrift für Geomorphologie, Supplementbände* Nr. 55(1), p. 1-13.
- DING, M.-Q., M.-Y. LU, C.-H. CUI, J. DING, J.-W. PANG, N.-Q. REN & S.-S. YANG (2023), ESSCC: A new multi-scale and extensively applicable evaluation system for the construction of sponge cities. *Sustainable Horizons* Nr. 8, p. 100069, <https://doi.org/10.1016/j.horiz.2023.100069>.
- EFRAG (2022), Draft European Sustainability Reporting Standards (ESRS 4). Biodiversity and ecosystems.
- EUROPEAN COMMISSION (2013), Communication from the commission to the European Parliament, the council, the economic and social committee and the committee of the regions. Green Infrastructure (GI) — Enhancing Europe's Natural Capital. COM/2013/0249 final. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52013DC0249>.
- EUROPEAN COMMISSION (2021), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Forging a climate-resilient Europe - the new EU Strategy on Adaptation to Climate Change, COM/2021/82 final, Directorate-General for Climate Action.
- EUROPEAN COMMISSION (2024a), The European Green Deal. Striving to be the first climate-neutral continent. Retrieved: 11.12.2024 Last, from

https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en.

EUROPEAN COMMISSION (2024b), Biodiversity strategy for 2030. Last, from https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en.

EUROPEAN ENVIRONMENT AGENCY (2002), Europe's biodiversity – biogeographical regions and seas. Nr. 1/2002.

EUROPEAN PARLIAMENT (2020), Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088 (Text with EEA relevance). <http://data.europa.eu/eli/reg/2020/852/oj>.

EUROPEAN PARLIAMENT (2021), Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law'). <http://data.europa.eu/eli/reg/2021/1119/oj>.

EUROPEAN PARLIAMENT (2024), Regulation (EU) 2024/1991 of the European Parliament and of the Council of 24 June 2024 on nature restoration and amending Regulation (EU) 2022/869 (Text with EEA relevance). <http://data.europa.eu/eli/reg/2024/1991/oj>.

GEIGER, R. (1954), Klassifikation der Klimate nach W. Köppen. Landolt-Börnstein – Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik und Technik. Berlin, Springer. Vol. 3, p. 603-607.

GEIGER, R. (1961), Die Köppen-Geiger/Klimate der Erde. Wandkarte. Überarbeitete Neuauflage von Geiger. Darmstadt, Pertes.

HOHENWALLNER, D., G.-M. SAULNIER, A. BRANCELJ, I. BERTONCELJ, M. BRENČIČ, A. BRUN, C. BRUNO, M. CADOUX-RIVOLLET, C. CALVI, M. CAROLLI, W. CASTAINGS, J. CHENUT, A. DE BONA, C. DEFRANCESCO, M. DOERING, E. DUTTO, G. FREUNDL, T. HARUM, A. JAMSEK, H. JANETSCHKEK, S. KLEMENČIČ-KOSI, H. KLUG, R. KOZEL, C. KOPEINIG, P. LACHENAL, S. LASCOURS, T. LESKOSEK, B. MAIOLINI, T. MEZEK, N. MIGNONE, N. MORI, C. MOUREMBLES, J. NEUWIRTH, P. PACCARD, A. PASCARIELLO, P. PERGHER, W. POLTNIG, M. PUŠENJAK, R. RAMPAZZO, C. RESZLER, C. ROBINSON, A. ROLLANDO, M. SALVARO, J. SCHLAMBERGER, R. SCUSSEL, M. SILIGARDI, G. SUETTE, V. VALENTAR, E. VAROLO, C. VECCELLIO, K. WAGNER, D. ZADRAVEC, P. ZALAVARI, H. ZESSAR & G. ZOLEZZI (2011a), Water Resources Management and Water Scarcity in the Alps: Recommendations for Water Resources Managers and Policy-makers. Interreg IVB, Alpine Space Programme, project 5-1-3-F. University of Savoie, Savoie.

HOHENWALLNER, D., G.-M. SAULNIER, W. CASTAINGS, A. ASTENGO, M. BRENČIČ, C. BRUNO, M. CAROLLI, J. CHENUT, A. DE BONA, M. DOERING, E. DUTTO, G. FREUNDL, T. HARUM, F. HOLZEIS, A. JAMSEK, S. KLEMENČIČ-KOSI, C. KOPEINIG, R. KOZEL, H. KLUG, S. LASCOURS, B. MAIOLINI, N. MIGNONE, J. NEUWIRTH, P. PACCARD, A. PASCARIELLO, P. PERGHER, W. POLTNIG, M. PUŠENJAK, R. RAMPAZZO, C. RESZLER, C. ROBINSON, A. ROLLANDO, M. ROSSO, M. SALVARO, J. SCHLAMBERGER, R. SCUSSEL, M. SILIGARDI, G. SUETTE, V. VALENTAR, E. VAROLO, C. VECCELLIO, K. WAGNER, D. ZADRAVEC, P. ZALAVARI, H. ZESSAR & G. ZOLEZZI (2011b), Water Management in a Changing Environment: Strategies against Water Scarcity in the Alps. Project Outcomes and Recommendations. Interreg IVB, Alpine Space Programme, project 5-1-3-F. University of Savoie, Savoie.

KLUG, H. & P. JENEWEIN (2010), Spatial modelling of agrarian subsidy payments as an input for evaluating changes of ecosystem services. *Ecological Complexity* Nr. 7(3), p. 368-377, <http://dx.doi.org/10.1016/j.ecocom.2009.12.005>.

KLUG, H., Z. DABIRI, B. HOCHWIMMER & P. ZALAVARI (2012), Assessing drinking water consumption by inhabitants and tourists in the Alps using a WebGIS for information distribution. *International Journal of Biodiversity Science, Ecosystem Services & Management* Nr. 8(1-2), p. 50-70, <https://doi.org/10.1080/21513732.2012.680499>.

- KÖPPEN, W. (1884), Die Wärmezonen der Erde, nach der Dauer der heissen, gemässigten und kalten Zeit und nach der Wirkung der Wärme auf die organische Welt betrachtet. Meteorologische Zeitschrift Nr. 1(21), p. 215-226.
- KÖPPEN, W. (1936), Das geographische System de Klimate. Gebrüder Borntraeger, Berlin.
- PARLIAMENT, E. (2000), Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000. Establishing a framework for Community action in the field of water policy. <http://data.europa.eu/eli/dir/2000/60/oj>.
- RIAHI, K., D. P. VAN VUUREN, E. KRIEGLER, J. EDMONDS, B. C. O'NEILL, S. FUJIMORI, N. BAUER, K. CALVIN, R. DELLINK, O. FRICKO, W. LUTZ, A. POPP, J. C. CUARESMA, S. KC, M. LEIMBACH, L. JIANG, T. KRAM, S. RAO, J. EMMERLING, K. EBI, T. HASEGAWA, P. HAVLIK, F. HUMPENÖDER, L. A. DA SILVA, S. SMITH, E. STEHFEST, V. BOSETTI, J. EOM, D. GERNAAT, T. MASUI, J. ROGELJ, J. STREFLER, L. DROUET, V. KREY, G. LUDERER, M. HARMSSEN, K. TAKAHASHI, L. BAUMSTARK, J. C. DOELMAN, M. KAINUMA, Z. KLIMONT, G. MARANGONI, H. LOTZE-CAMPEN, M. OBERSTEINER, A. TABEAU & M. TAVONI (2017), The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Global Environmental Change Nr. 42, p. 153-168, <https://doi.org/10.1016/j.gloenvcha.2016.05.009>.
- SONG, C. (2022), Application of nature-based measures in China's sponge city initiative: Current trends and perspectives. Nature-Based Solutions Nr. 2, p. 100010, <https://doi.org/10.1016/j.nbsj.2022.100010>.
- WANG, M., H. YUAN, D. ZHANG, J. QI, Q. RAO, J. LI & S. KEAT TAN (2023), Supply-demand measurement and spatial allocation of Sponge facilities for Sponge city construction. Ecological Indicators Nr. 148, p. 110141, <https://doi.org/10.1016/j.ecolind.2023.110141>.
- YANG, M., D. CHEN, L. SHI, J. HE, L. LIU & X. SHANG (2022), How do construct a sponge city that can improve residents' satisfaction? Evidence from a suburb of Huizhou City, China. Ecological Indicators Nr. 142, p. 109238, <https://doi.org/10.1016/j.ecolind.2022.109238>.
- YUAN, Y., Y. ZHENG, X. HUANG & J. ZHAI (2024), Climate resilience of urban water systems: A case study of sponge cities in China. Journal of Cleaner Production Nr. 451, p. 141781, <https://doi.org/10.1016/j.jclepro.2024.141781>.
- ZHANG, Z. (2022), Can the Sponge City Project improve the stormwater drainage system in China? —Empirical evidence from a quasi-natural experiment. International Journal of Disaster Risk Reduction Nr. 75, p. 102980, <https://doi.org/10.1016/j.ijdrr.2022.102980>.

❖ **Table of Abbreviations**

While implementing the project deliverable, acronyms and abbreviations are repeatedly referred to. The long form is listed in the text at its first use and listed here again alphabetically.

BGR: biogeographical regions	7	FAO: Food and Agriculture Organisation	19
CC: climatic conditions	7	PP: project partner	10
DR: Danube Region	6	PSPT: Pilot Site Picture Tool	10
DRB: Danube River Basin	13	Sen2Cube: Sentinel Data Cube	32
EO: Earth Observation	6		

Index

To quickly find individual passages in this deliverable using keywords, the following index was automatically generated using individual tags in the text.

biogeographical regions	7	geographical characteristics	12
Climate Change	6	MS Forms	10
climate conditions	7	Pilot Site Picture Tool	10
Danube Region	6	pilot sites	7
Danube River Basin	13	raingarden	6
Earth Observation	6	Survey 1	10
ecosystem services	32	Survey 2	10
FAO	19		