Publizierbarer Endbericht

Gilt für Studien aus der Programmlinie Forschung

A) Projektdaten

Allgemeines zum Projekt	
Kurztitel:	CONQUAD
Langtitel:	Consequences of adaptation: Assessing multi-benefits and challenges in the transfer to more resilient and sustainable urban water systems
Zitiervorschlag:	Kleidorfer, Manfred; Back, Yannick, Jasper-Tönnies, Alrun; Einfalt, Thomas; Kinzel, Heiko; Urich, Christian (2020): CONQUAD - Consequences of adaptation: Assessing multi-benefits and challenges in the transfer to more resilient and sustainable urban water systems, Final Report, https://www.uibk.ac.at/umwelttechnik/research/projects/conquad/conquad.html
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Allgemeines zum Projekt	
Schlagwörter:	Siedlungswasserwirtschaft, Starkregen, Hitze, Klimawandelanpassung, Temperatur, Modellierung, GIS, Regenwassermanagement, Nature-Based-Solutions
Projektgesamtkosten:	302.351,56 €
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B) Project Overview

1 Kurzfassung

Angesichts der Herausforderungen, die der Klimawandel mit sich bringt, sehen sich Städte mit einer Zunahme der Starkregenereignisse sowohl in Intensität als auch Häufigkeit konfrontiert. Zur Anpassung an sich ändernde Randbedingungen ist es notwendig, Anpassungsmaßnahmen in der Entwässerung vorausschauend und nachhaltig zu planen. Ein gut konzipiertes Entwässerungssystem sorgt für hygienische Bedingungen, bewahrt die Qualität von Flüssen und Grundwasser, vermeidet Betriebsprobleme und verhindert oder reduziert Überschwemmungen. Diese Grundlagen des städtischen Abwassermanagements werden von der Stadtbevölkerung als selbstverständlich vorausgesetzt.

Die sich ändernden Niederschlagseigenschaften erhöhen jedoch den Druck auf das städtische Entwässerungssystem, was zu einer Zunahme von Überstauhäufigkeiten, Mischwasserentlastungen und Überflutungsereignissen führt. Um den Druck auf das städtische Entwässerungssystem zu verringern, hat bereits eine Verlagerung hin zu stärker dezentralisierten Regenwasserkonzepten in städtischen Gebieten begonnen. Solche dezentralen Maßnahmen leiten den Oberflächenabfluss nicht in die Kanalisation ein, sondern speichern, verdunsten und versickern ihn vor Ort. Die Konsequenzen einer derartigen Systemänderung, wie die Verbesserung des lokalen Mikroklimas sind das Thema dieses Projektes.

Ziel des Projektes CONQUAD war es, die Folgen der Anpassung städtischer Entwässerungssysteme an den Klimawandel zu analysieren. Dazu wurden die Auswirkungen des Klimawandels auf kurze, intensive Niederschlagsereignisse ermittelt, die für städtische Überflutungsereignisse relevant sind. Da Abflussprozesse auf versiegelten städtischen Flächen schnell ablaufen, ist eine zeitliche Auflösung der Niederschlagsinformation im Bereich von Minuten erforderlich. Mit diesen Daten wurden die Auswirkungen erhöhter Niederschlagsintensitäten auf das städtische Überflutungsrisiko ermittelt und mit den Auswirkungen eines erhöhten Abflusses aufgrund von Flächenversiegelung verglichen. Als weitere Auswirkung des Klimawandels wurden die Zunahme von Hitzetagen und die Auswirkungen auf das städtische Mikroklima und die bioklimatischen Bedingungen untersucht. Aus der Kombination dieser beiden Effekte wurde im Anschluss analysiert wie ein dezentrales Regenwassermanagement in der Lage ist, beide Effekte abzuschwächen. Die Idee solcher Regenwasserbehandlungssysteme besteht darin, Regenwasser zu speichern, zu versickern und zu verdunsten, anstatt es in eine Kläranlage abzuleiten. Diese Maßnahmen tragen auch dazu bei, den städtischen Hitzeinseleffekt zu verringern und das Mikroklima zu verbessern. Durch die Analyse der Landnutzungsmerkmale der Stadt wurden verschiedene Stadtstrukturtypen von Industrie bis Wohnen definiert und für jeden Typ die geeigneten blau/grünen Lösungen ermittelt.

Als Fallstudie für diese Arbeit wurde die Stadt Innsbruck verwendet, so dass die Analyse der Auswirkungen des Klimawandels im interessanten Fall einer alpinen Stadt durchgeführt wurde. Während der gesamten Projektlaufzeit wurde ein kontinuierlicher Informationsfluss zwischen dem Projektteam und den lokalen Akteuren sichergestellt. Die Ergebnisse dieses Projekts zum städtischen Mikroklima waren besonders interessant für den Anpassungsplan der Stadt an den Klimawandel und führten zu einem Folgeprojekt, das ebenfalls vom Österreichischen Klimafonds finanziert wird, dem Projekt cool-INN im Rahmen des Smart City-Programms, in dem blau-grüne Maßnahmen der städtischen Kühlung demonstriert werden sollen.

2 Executive Summary

With the challenges posed by climate change cities are facing more frequent and extreme rain events causing severe floods. A well-guided adaptation through new water management practices increases the sustainability and resilience of water services. A well-designed drainage system maintains hygienic conditions, protects water quality, avoids operational problems and prevents or reduces flooding. These fundamentals of urban wastewater management are taken for granted by the city's population.

However, the changing precipitation characteristics increase the pressure on the urban drainage system, leading to surcharge frequencies, combined sewer overflow frequencies and volumes and finally to severe urban floods, making it more difficult to meet these requirements. To reduce the pressure on the urban drainage system, a shift towards more decentralised stormwater systems in urban areas has already started. However, the unintended consequences of such measures, positive and challenging in nature are not well understood. Positive effects of decentralised stormwater systems are for example an increased amenity due to positive effects of green infrastructure on the urban microclimate or an improved groundwater balance as on-site infiltration is closer to the natural water cycle.

The aim of the project CONQUAD was to analyse consequences of adaptation of urban drainage systems to climate change. Therefor we analysed impact of climate change on short, intense rainfall events as these events are relevant for urban flooding. As runoff processes on sealed urban surfaces are fast, a temporal resolution of minutes is required. After that we analysed impact of increased rainfall intensities on urban flood risk and compared this risk to impact of urban development. As a further effect of climate change we analysed increase of heat days and impact on the urban microclimate and bioclimatic conditions. Having these effects, we analysed how decentralised stormwater management is able to mitigate both effects. The idea of such blue-green rainwater treatment systems is to store, infiltrate and evaporate rainwater instead of draining it to a wastewater treatment plant. These measures also help to reduce the urban heat island effect and to improve the microclimate. By analysing the city's land-use characteristics

different urban structure types from industrial to residential were defined and for each type, the suitable blue-green solutions are identified.

As case study for this work the city of Innsbruck was used, so the analysis of climate change effects was done in the interesting case of an Alpine city. During the entire project period, a continuous information flow between the project team and local stakeholder was ensured. The findings of this project on urban microclimate were especially interesting for the city's climate change adaptation plan and resulted in a follow up project, which is also funded by the Austrian Climate Fund, the project cool-INN, in the Smart City program, in which blue-green measures of urban cooling shall be demonstrated.

3 Background and Aim

With the challenges posed by climate change cities are facing more frequent and extreme rain events causing severe floods with often devastating consequences, long periods of draught impacting the reliable provision of water, and more frequent and extreme heat waves with severe impacts on the well-being of citizens particularly in vulnerable communities. Besides efforts of the global community to reduce CO2 emissions to mitigate climate change impacts, an adaptation of the urban water system is vital to provide essential water services reliably under more extreme climatic conditions for a sustainable future development of urban areas (Arnbjerg-Nielsen and Fleischer, 2009). A well-guided adaptation through new water management practices can provide economic opportunities in vulnerable sectors while increasing the sustainability and resilience of water services and urban environments.

A key objective of such a successful adaptation is to reduce existing vulnerabilities of the urban water systems to climate change and changes in the urban environment, while increasing the capability to provide additional ecosystem services such as the reduction of environmental impacts or increased amenity and the reduction of urban heat islands (UHIs) through blue-green infrastructure systems (Brown et al., 2009). Hence, adaptation in synergy with mitigation is a crucial response strategy to improve the resilience of our cities (Stern et al., 2006, Rijke et al., 2013) and to avoid tipping points in cities (Lenton, 2011). The ACRP project "DynAlp - Dynamic Adaptation of Urban Water Infrastructure for Sustainable City Development in an Alpine Environment" showed that to maintain current service levels an adaptation of the existing infrastructure is required (Urich and Rauch, 2014). Different adaptation measures and their potential to mitigate negative impacts were tested. These included traditional technical measures as for example the increase of flow capacity of drainage pipes but also more environmentally friendly measures as the implementation of green infrastructure often denoted as water sensitive urban design (WSUD) or low impact development (LID)(Fletcher et al., 2014). Such decentralised technologies are increasingly popular in the context of adaptation as they are expected to be more flexible and resilient to future changes and challenges (Hoyer et al., 2011, Grant et al., 2012, Fletcher et al., 2014). Not only providing a robust response strategy to an uncertain future, but also additional benefits reducing environmental impacts and increasing urban amenity improving the liveability of urban environments (Zhou et al., 2013). As the project DynAlp successfully showed, an effective response strategy for future challenges combines centralised and decentralised infrastructure to maximise the advantages of both systems (Kleidorfer et al., 2015).

However, the consequences of such measures, positive and challenging in nature were not well understood. It was therefore necessary to investigate which effects are caused by anticipated adaptation strategies and to which extend it is possible to mitigate different effects of climate change (increased rainfall intensities and increase of heat days), using the same solutions.

The objectives of this project for the case study Innsbruck were to:

- evaluate climate projections from different regional climate models with respect to extreme precipitation and heat events,
- evaluate changing precipitation characteristics,
- evaluate increase of heat days,
- evaluate drainage capacity and flood risk, considering more frequent and extreme precipitation events,
- evaluate multi-beneficial use of decentralised stormwater management systems, with a greater focus on improving the urban microclimate,
- evaluate the scale effect and geographical location on adaptation measures and
- improve decision support for stakeholders, politicians and spatial planners.

4 Content and Results

Case Studies & end-user consultation (WP 1)

Case study description

Case study in this project is the city of Innsbruck, the capital of Tyrol in western Austria. Innsbruck is situated in the Inn-valley at an altitude of approximately 574m.a.s.l. With a surface area of 36.6km^2, the city comprises different structure types of varying density and height and is populated by 132.110 people. The cities drainage system consists of a combined sewer system, with a network length of approximately 250km and a total catchment area of approximately 2500ha (see Figure 1). Situated in the middle of the Alps, climatic conditions in the city of Innsbruck are characterised by cold winters and strong precipitation events during the summer period. Annual mean air temperature is 10.3°C, considering the period 1981 to 2010 (ZAMG, 2020). However, during the year temperatures can drop below 0°C within winter and exceed 25°C within summer months. With climate change altering global and local precipitation and temperature patterns, extreme weather phenomena will occur more frequent. As temperatures on a global scale have already increased by approximately 1°C compared to pre-industrial levels (period between 1850 and 1900), temperatures in the European alpine region have risen at a rate twice as large (Auer et al., 2007).

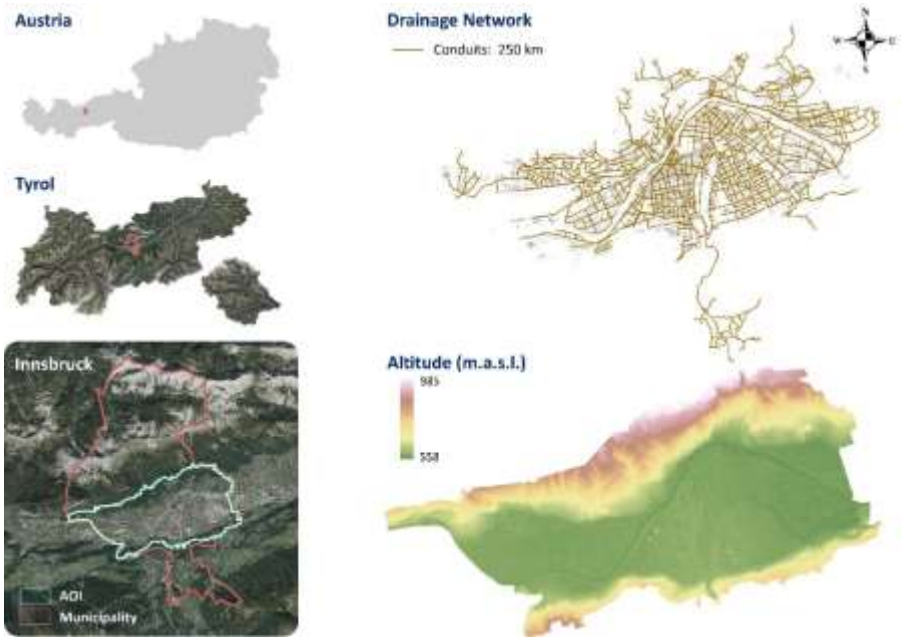


Figure 1. Location of the case study Innsbruck, the citys drainage network and altitude.

<u>End-user consultation</u>

In WP1 the communication with local stakeholder relevant for the case study was organized. For the case study Innsbruck that are Innsbrucker Kommunalbetriebe AG (IKB) as the company responsible by operating the city's drainage system. The company is 100% owned by the city of Innsbruck. At the city level the relevant stakeholders are the spatial planning department, the team responsible for the climate change adaptation plan and political representatives. In WP1 continuous communication with city representatives and representatives from IKB was ensured mainly in smaller meetings and workshops instead of larger dissemination events in order to enable better discussions. The project was also presented at city workshops for developing the city's climate change adaptation plan and project representatives were invited as experts to a city council meeting.

As part of WP1 also the Web-GIS was developed, which is necessary to visualize the project data during workshops:

Impact assessment and adaptation (WP 2)

<u>Mean and seasonal precipitation</u>

Change signals of the mean precipitation and extreme daily sums, averaged over eight regional climate models, are presented in Figure 2. Average changes of seasonal precipitation are displayed in Figure 3 for the scenario RCP8.5. When comparing the near future 2021-2050 and the reference period, differences of annual mean precipitation are relatively small in the model average. A comparison of the seasonal precipitation rates reveals a shift with increased precipitation in spring and autumn and a decrease in summer precipitation (see Figure 3). In contrast to the mean precipitation, extreme daily precipitation tends to increase in the near future. The climate change signal of the 99% percentile of precipitation of all days is displayed in Figure 2 and in Figure 4 showing the average and seasonal changes (note the different colour scale in Figure 4- seasonal changes). The projected increase of extreme daily precipitation is relatively homogeneous throughout the year and does not reproduce the seasonal variation of mean precipitation. E.g. in summer, mean precipitation is expected to decrease while there is a positive trend of extreme daily precipitation.

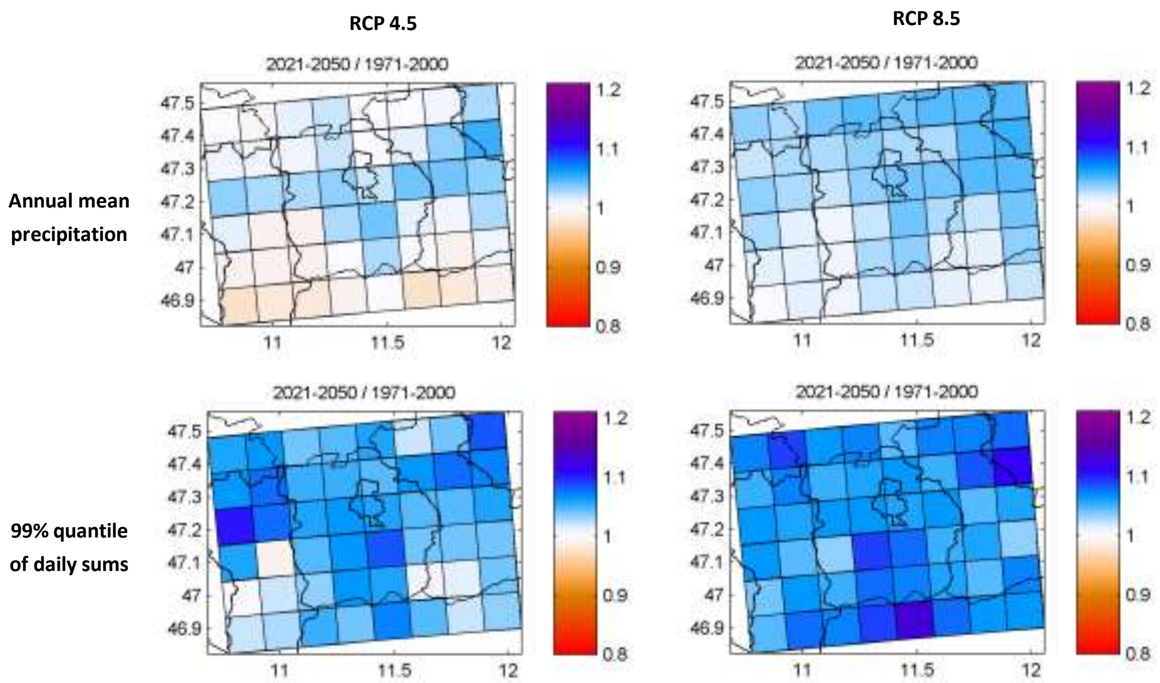


Figure 2. Climate change signals of mean precipitation and extreme daily sums (99% quantile) for the near future 2021-2050 relative to 1971-2000 as ensemble average of 8 regional climate projections.

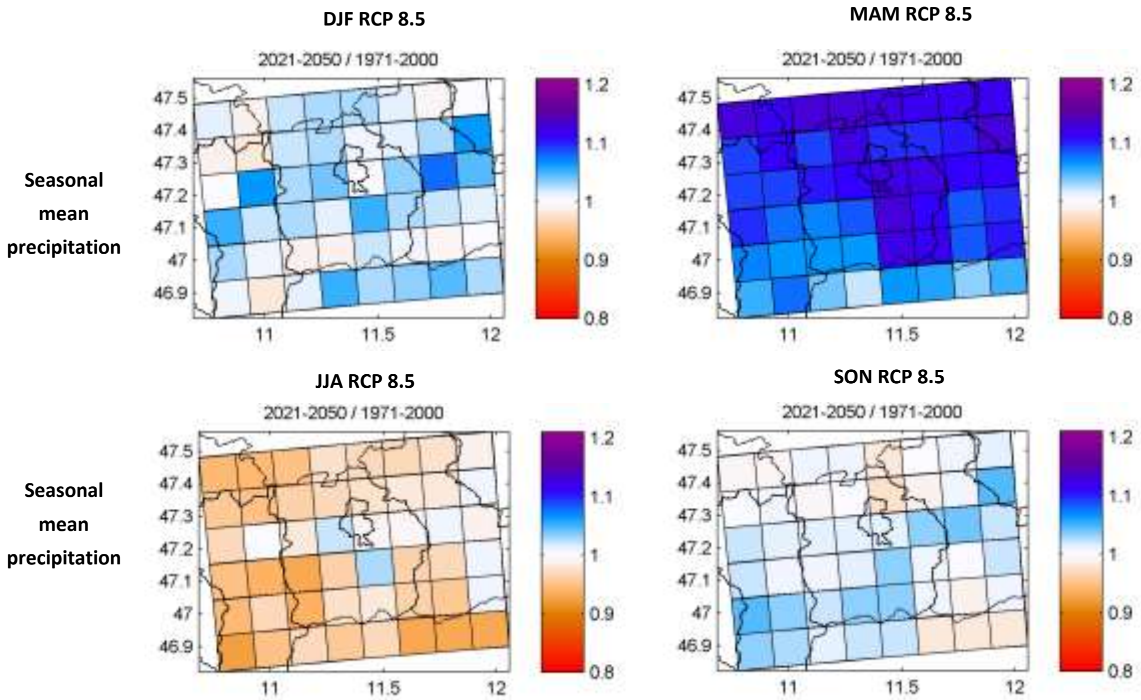


Figure 3. Climate change signals of mean seasonal precipitation for 2021-2050 compared to 1971-200 in the RCP Scenario 8.5 as ensemble average of 8 regional climate projections.

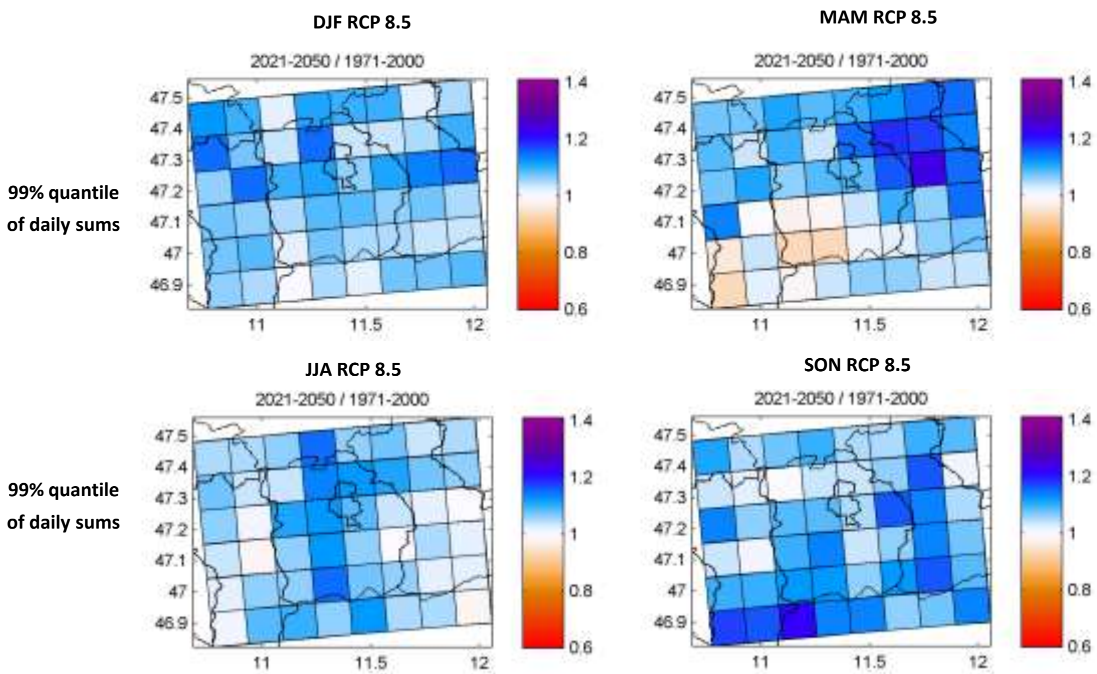


Figure 4. Climate change signals of seasonal extreme daily precipitation (99% quantile) for 2021-2050 compared to 1971-200 in the RCP Scenario 8.5 as ensemble average of 8 regional climate projections.

Spatial structure

The regional climate simulations reproduce roughly the large-scale structure of the observed precipitation, with large differences of the annual mean precipitation in the considered area. However, projected precipitation changes are relatively uniform. A few models show regional patterns of the seasonal trends in spring and autumn, with a tendency to a higher precipitation increase in the northern area and a lower increase or no change in the southern part (south of the Inn valley). But inter-model differences are high and do not allow a robust statement about local differences of future precipitation trends. The non-homogeneity among the regional climate models may be related to the fact that the models with the current resolution do not depict all relevant processes in the complex Alpine terrain regarding cloud formation and precipitation.

Sub-daily extreme precipitation

Climate change signals of sub-daily extreme precipitation were calculated using the output of the statistical downscaling. Based on statistical extreme precipitation heights with return periods up to 100 years, relative changes were determined as ratio between the near future and the reference period, differentiated by the event duration. Results are presented in Table 1 for return periods 5, 20, and 100 years under the scenario RCP8.5. Looking at the near future, differences between the RCP-scenarios RCP4.5 and RCP8.5 are small in respect to mean and extreme precipitation trends. Regarding extreme precipitation events with a short duration up to 90min, mean change signals are mostly between 2% and 4%. For longer durations between 2h and 12h, increases are higher with approximately 4%-8%, depending on the duration and return period. The range given by the minimum and maximum of the eight regional climate simulations reveals large differences between the simulations, with decreases up to -15% and increases up to +29%.

These different outcomes relate partly to different changes of mean/seasonal precipitation in the regional climate simulations. Figure 5 displays the results of extreme precipitation (duration 4h, return period 20 years) of 8 individual climate simulations against the climate signals of air temperature and mean precipitation. Events of a shorter duration of 1h (return period 20 years) against the climate signals of air temperature and mean summer precipitation are shown in Figure 6. An increase of the 4h extreme precipitation occurs in 12 of 16 simulations under both the scenarios RCP4.5 and RCP8.5 while a decrease occurs in only 2 simulations. There is no apparent relationship between the 4h extreme precipitation trend and the climate signals of air temperature or mean precipitation. Events of extreme precipitation with a duration of 1h (Figure 6) show less significant trends in the model average. A potential explanation is the seasonality of small-scale convective precipitation events which mainly occur during summer. Increases of 1h extreme precipitation occurs in simulations with constant or increasing summer precipitation while negative trends occur in simulations with a decreasing summer precipitation.

For the impact assessment in order to evaluate change of flood risk caused by changed rainfall intensities a hydrodynamic sewer model (SWMM) was used.

Table 1. Climate change signals of extreme sub-daily precipitation for statistical return periods 5, 20, and 100 years at different event durations, presented as relative changes for 2021-2050 compared to 1971-2000. The ensemble mean change signals are specified as well as the minimum and maximum from 8 regional climate projections after statistical downscaling to the station scale.

return period / duration	*RCP 8.5*		
	5 years	**20 years**	**100 years**
10 min	-10% 1 % 4 %	-6% 2% 5%	-13% 3% 11%
60 min	-10% 2 % 3%	-10% 3% 7%	-13% 2% 9%
90 min	-7% 2 % 6%	-7% 3% 9%	-15% 4% 15%
2 h	-5% 3 % 7%	-5% 3% 10%	-15% 7% 22%
4 h	-1% 4 % 7%	0% 3% 17%	-6% 5% 29%
6 h	1% 6 % 11%	1% 6% 14%	-8% 6% 24%
12 h	3% 8 % 16%	0% 8 % 11%	-2% 5 % 24%

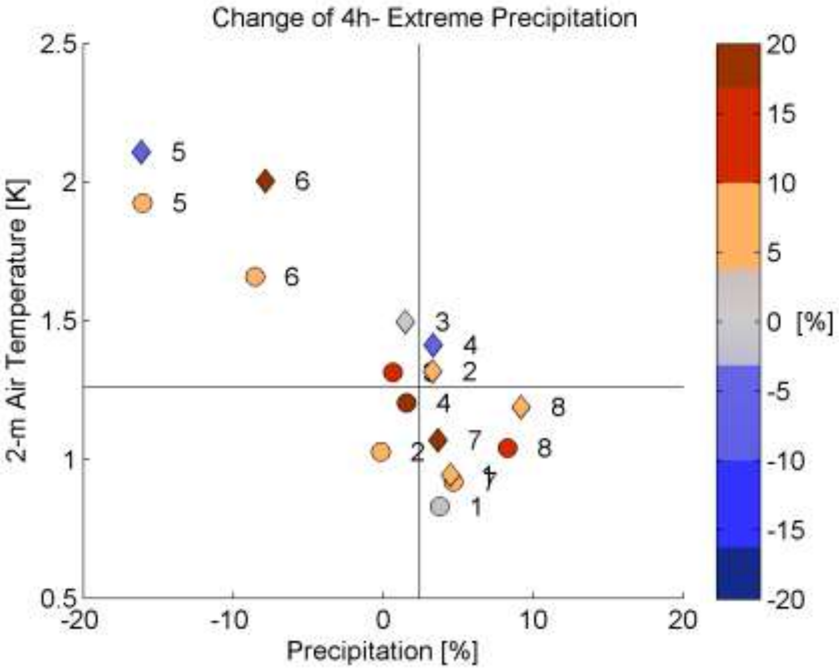


Figure 5. Percental change of sub-daily extreme precipitation (duration 4 h) with respect to the climate signals of air temperature and precipitation under the scenarios RCP4.5 (circles) and RCP8.5 (diamonds) for the near future 2021-2050 relative to the reference period 1971-2000.

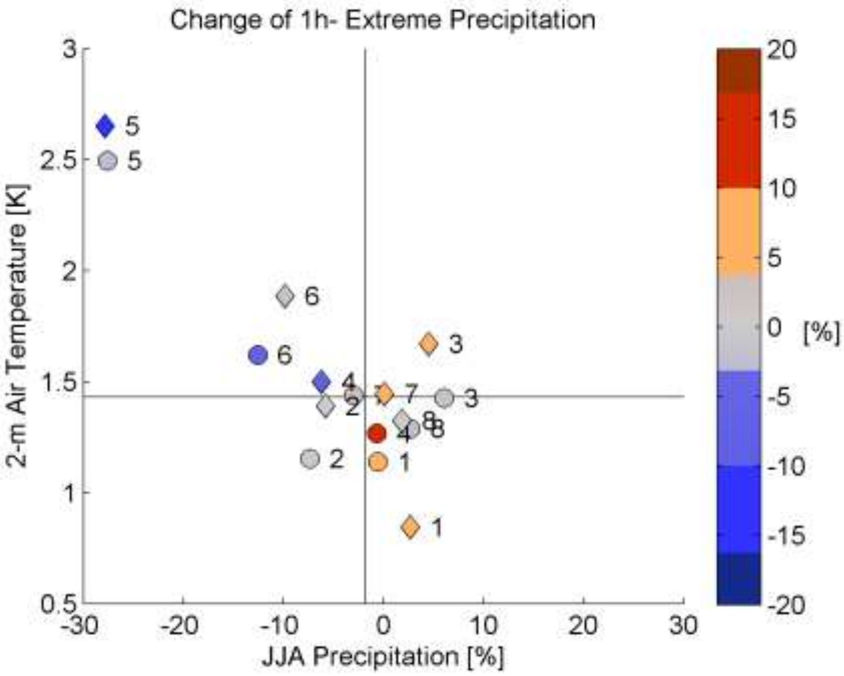


Figure 6. Percental change of sub-daily extreme precipitation (duration 1 h) with respect to the climate change signals of air temperature and summer precipitation (JJA) under the scenarios RCP4.5 (circles) and RCP8.5 (diamonds) for the near future 2021-2050 relative to the reference period 1971-2000.

Temperature scenarios

The occurrence and intensity of rising temperatures and the frequency of excessive heat events (EHE) per year depend on the location and the considered RCP scenario. Climate change scenarios are analysed using the ensemble of regional climate simulations from EURO-CORDEX/ ReKliEs in Table 2. Regarding the number of days with a daily maximum temperature exceeding 30°C reveals a relatively small increase and little scenario differences until 2050 and a strong increase in RCP8.5 based simulations towards the end of the century (Figure 7). In the second half of the century, the spread among the scenarios outweighs the spread between individual models.

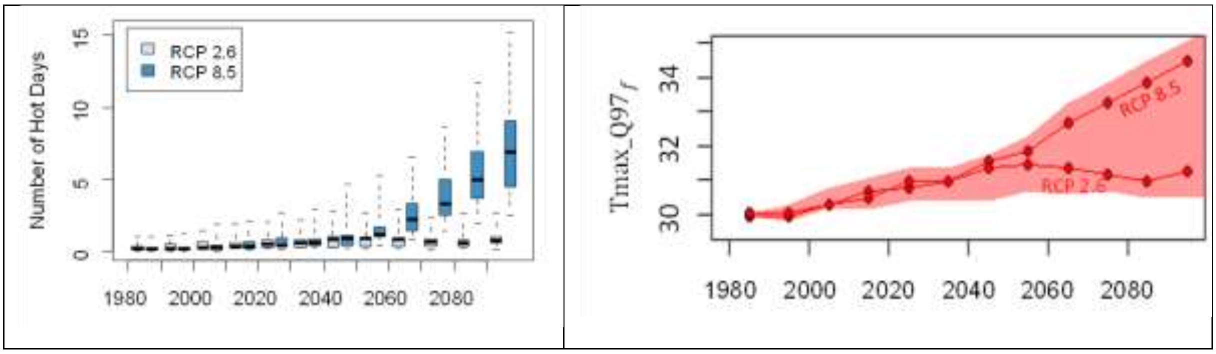


Figure 7. On the left-hand site: Average number of Hot Days (daily maximum air temperature >30°C) per year in EURO-CORDEX/ ReKliEs projections with the scenarios RCP2.6 and RCP8.5. The boxplots illustrate the ensemble spread, whiskers extend to the minimum and maximum of the simulations. Values are averaged over 30 years and 6 RCM grid points around Innsbruck, Tyrol. On the right-hand site: Projected change of the 97% quantile of daily maximum temperatures Tmax_Q97 at Innsbruck stations, based on RCP2.6 and RCP8.5 simulations. The shaded area comprises 85% of the RCP2.6 and RCP8.5 simulations.

This increase in frequency at a fixed temperature threshold can be converted to a temperature increase by specifying a fixed probability threshold. We regard the 97%-quantile of daily maximum temperatures T_{max}_Q97, which corresponds to the number of hot days at the station level in the reference period. The change of T_{max}_Q97 displays the same overall picture as the change of the number of hot days (Figure 7). Until the end of the century, T_{max}_Q97 is projected to increase by 1.0K in RCP2.6 simulations and by 3.9K in RCP8.5 simulations. For the period 2021-2050, the scenario difference is almost negligible.

For the period 2071-2100, under the scenario RCP8.5 T_{max}_Q97 is likely to rise by +3.4K to +5.1K (15%-85% percentiles) with a median of +3.9K. Under the RCP2.6 scenario, the projected range is +0.5K to +1.4K (median: +1.0K). Regarding the number of hot days above 30°C at the station level, this corresponds to an increase of the exceedance frequency of +20% to +70% under the RCP2.6 scenario and to an increase with a factor of three to five under the RCP8.5 scenario compared to the reference period.

These differences result in temperatures T_{max}_Q97 of 31°C for 2035 and 2085 with the scenario in RCP2.6 and 31°C and 33.9°C for 2035 and 2085 respectively with the scenario in RCP8.5.

Scale effect of adaptation (WP 3)

Decentralised stormwater management systems can be introduced on three different scales within a city: (1) Sewer catchment area, (2) District scale and (3) Property scale (Matzinger et al., 2017). Depending on the scale, different systems are more suitable. Depending on the system, the occurring consequences (both positive and challenging in nature) create effects from a local to a city-wide scale. Analysing the effects of different decentralised stormwater techniques on a district scale, highlights the importance of urban form and accompanying surface characteristics in the emerging processes. Different techniques involving natural processes (e.g. infiltration, evapotranspiration, retention, etc.) are differently more suitable for specific urban settlement structures (Kleidorfer et al., 2019). Therefore, we introduced a Settlement Structure Type Approach (SSTA), modified after Simperler et al. (2018), to evaluate variable urban structure types and their potential and constraints for decentralised stormwater management and focused our studies on different urban forms in the city of Innsbruck. Although setting the focus of the study on urban forms in a specific city, the approach is replicable and applicable in any urban environment from a small municipality to a big city, with respect to their geographic locations and climatic conditions. Furthermore, specific results for different urban forms on a district scale can also be resampled for statements on a city-wide scale. Based on high-resolution orthoimagery derived from satellites, ten different settlement structure types (see enumeration below) are assigned to the case study Innsbruck, using the commercial software ESRI ArcMap v10.6.1 (ESRI, 2019). The Settlement Structure Types (SST) are drawn manually as polygons (See Figure 8) and are afterwards clipped to a building layer for further spatial analysis (see Figure 9). By having the information about SST for single buildings, it is possible to render a more accurate area calculation on a property scale.

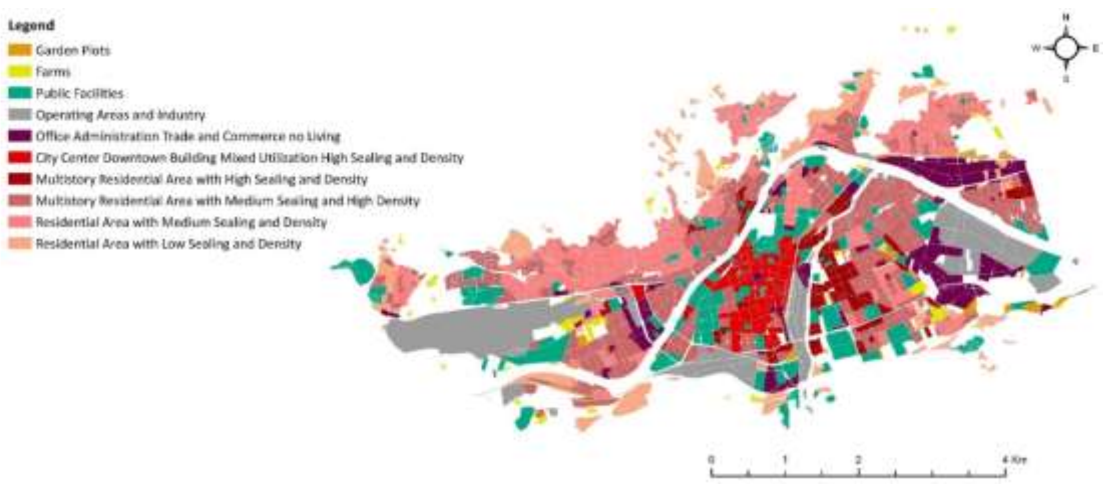


Figure 8. Settlement Structure Types for the city of Innsbruck - District level.

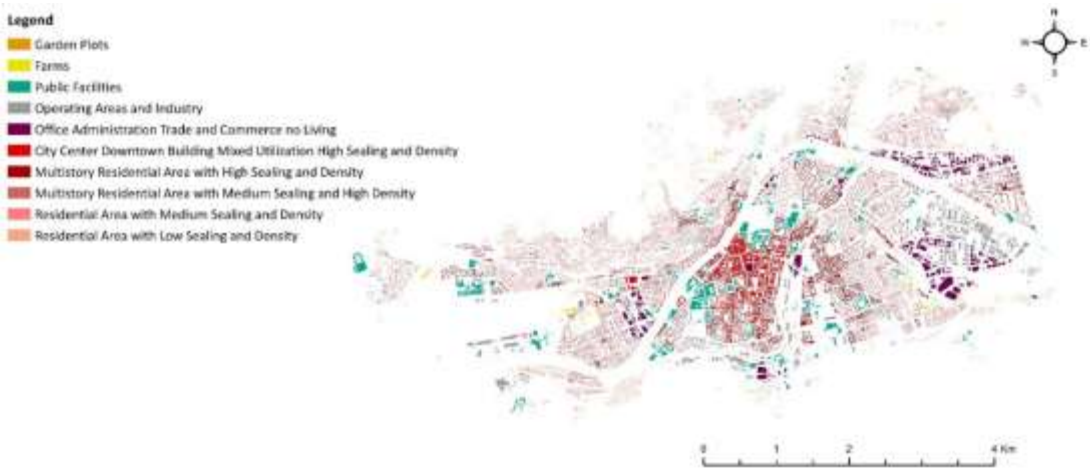


Figure 9. Settlement Structure Types for the city of Innsbruck - Building level.

Based on the SST, it is possible to give recommendations for different decentralised stormwater techniques (Simperler et al., 2018 and Kleidorfer et al., 2019). The following statements can be made: (+) Recommended, (o) Permitted, (-) Not Recommended, (i.A.) Individual Assessment Necessary. Table 2 represents nine different decentralised stormwater techniques in relation to the ten different SSTs.

Table 2. Recommendations for nine different decentralized stormwater techniques, based on ten different SSTs.

	Decentralized Stormwater Techniques								
Settlement Structure Types	Retention and Drainage	Retention and Evapotranspiration	Retention and Utilization	Infiltration with mineral filter	Infiltration with lawn	Infiltration with ground filter	Infiltration with technical filter	Drainage above ground	Drainage underground
Garden Plots	o	+	+	o	+	+	+	o	o
Farms	o	+	+	-	-	+	i.A.	i.A.	i.A.
Public Facilities	o	+	+	i.A.	o	+	o	o	o
Operating Areas and Industry	o	i.A.	+	-	-	o	i.A.	i.A.	i.A.
Office Administration Trade and Commerce no Living	o	+	+	-	o	+	o	i.A.	o
City Centre Downtown Building Mixed Utilization High Sealing and Density	o	i.A.	+	-	-	+	o	i.A.	o
Multistory Residential Area with High Sealing and Density	o	+	+	i.A.	+	+	+	o	o
Multistory Residential Area with Medium Sealing and High Density	o	+	+	o	+	+	+	o	o
Residential Area with Medium Sealing and Density	o	+	+	o	+	+	+	o	o
Residential Area with Low Sealing and Density	o	+	+	o	+	+	+	o	o

Utilising ESRIs ArcMap v10.6.1 (ESRI, 2019) and high spatial accuracy imagery obtainable from flyover techniques, radiometric and geometric data was generated to create a multi-functional classification of urban land cover. Consequently, statements can be made considering the degree of sealed and vegetated surfaces for every specific SST. The methodology and results for the multi-functional classification of urban land cover can be found in the peer-reviewed paper: *Hiscock, O., et al. (2020). A GIS-based land cover classification approach suitable for fine-scale urban water management* in the journal Water Resource Management.

These results have been published in Hiscock, O., et al. A GIS-based land cover classification approach suitable for fine-scale urban water management. Water Resource Management, 2020. [9]

Resampling the results of the classification for every single SST for statements on a city-wide scale, hot-spots of sealed surfaces can be depicted (Figure 13). Figure 13 shows the degree of sealed surfaces within a 50m x 50m grid for the city of Innsbruck. Hot-spots are mainly occurring within the SSTs "city centre downtown building, mixed utilisation high sealing and density", "office administration trade and commerce, no living", "operating areas and industry" and "multistorey residential area with high sealing and density". These areas show a degree of sealed surfaces above 80%.

In the upcoming section we evaluate the consequences of adaptation measures in the city of Innsbruck. Considering future climate change scenarios for both precipitation and temperature patterns, the focus is set: (1) on the effects of the new regional planning program (ÖROKO 2.0) and the accompanying land cover changes on the existing drainage network system and (2) on the effects of decentralised stormwater systems and blue-green infrastructure on urban microclimatic and bioclimatic conditions.

Evaluating consequences of adaptation (WP 4)

Within this section, we assess the consequences of adaptation measures in the transfer to more resilient and sustainable urban water systems. To be able to cope with future challenges, long-term strategies need to be implemented into the cities' development plans. Determining future land use designations and development areas, these plans are a powerful tool and contemporaneous influence and support adaptation measures. However, communication between the different parties is lacking vital information exchange. This issue becomes visible when analysing the development process of the new regional planning program for Innsbruck (ÖROKO 2.0). By the end of 2012, the regional planning program for Innsbruck (ÖROKO, 2002) expired in its validity (Stadt Innsbruck, 2002). After the transition period was extended twice, a first draft of the new, continuative regional planning program (ÖROKO 2.0) could finally be presented in summer 2017. It is conceived by the planning association of Innsbruck and its surrounding (www.piu.gv.at) and regulates the regional development for the immediate future of the city of Innsbruck. The existence of a valid regional planning program is condition for legitimated land use designations for any area. It is subordinated to the Tyrolean regional planning act (TROG, 2016) and contains mandatory definitions about land utilisation on a very detailed level of parcels. The new program is valid in the period between the years 2015 and 2025, thus 10 years. Issues of multiple interests, which have already been pinned in the previous program, are maintained and traced further, e.g. commercial, social or energy issues. A "responsible and economically allocation of land and other natural resources" (Stadt Innsbruck 2017) is defined as a paramount objective. Hence, the city development is rather aiming for densification than expansion. The ÖROKO 2.0 defines 53 zones with a summed-up area of approximately 217ha as so called "structural development areas". They are assigned to different planning attributes such as a demand period, utilisation category, development category and a targeted site density. The most general attribute is the development class. A development zone is either designed as an expansion, restructuring or densification zone.

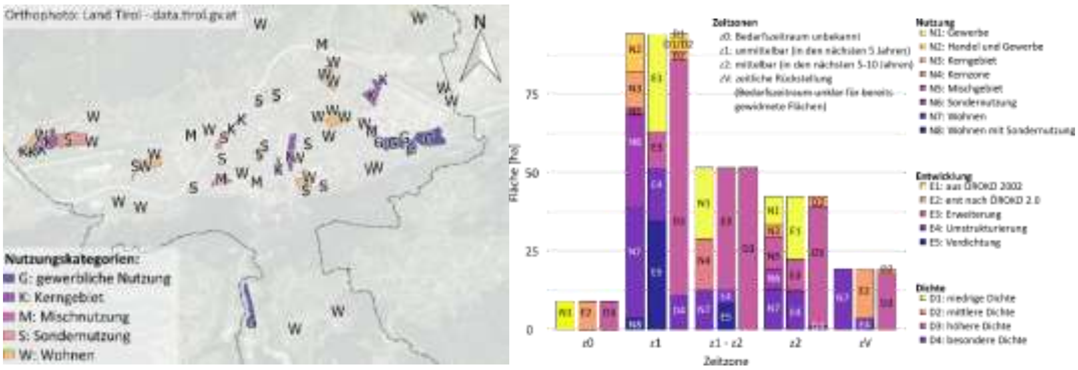


Figure 10. Structural development areas a) according to their utilization category and b) divided according to their area and their sequence in development.

The major part of the designated development areas is intended for the contemporary establishment of new living space (within the next 5 years). The second largest portion within the next 5 years (special utilisation) will be available e.g. for the creation of educational and health care institutions. Mobilisation, restructuring and expansion of commercial and core areas is scheduled later. For little more than 50ha (mostly areas for commercial use) it is not yet fixed when their planned development will be executed within the next 5 to 10 years. Only one zone (the goods depot of Innsbruck) with its 9ha is still completely undefined. Thus, this zone might be included in the next regional planning program(s) and its development might probably happen after the validity of the current regional planning program.

From an urban drainage perspective, the major challenges occur due to newly developed areas and densifications within existing developed lots. In sum, approximately 60ha are designated as expansion zones. They are located rather periphery to the city and currently mostly empty. Targeted building densities (D1-D3) are based on designed densities of effective areas or construction mass. Areas allocated to D4 (special density) will be assigned to a building density in an individual assessment. 192 of 217ha are allocated to category D3, the highest possible assignment. This shows the strong quest to an increase of very densely developed areas.

Decisions in a spatial planning process depend on many different factors, e.g. the local geography, the city's economic situation but also more immediate issues such as migration and emigration have to be considered. Innsbruck is located in the middle of the Alps in the valley of the river Inn. Therefore, its geographic boundaries are marked very clearly and stringent. The available habitable area is thus one of the biggest challenges for spatial planning.

The cadastral area of Innsbruck amounts to approximately 105km². Less than one third of it is yet used as building area. Other 30km² consist of Alps, rocks, boulders and miscellaneous other devastated areas (BEV 2016). The highest point within city boundaries is on an altitude of 2642m.a.s.l., whereas the major part of the settlement area is located at an altitude of approximately at 570m.a.s.l. This area is characterised by a population density of approximately 5000 inhabitants per km² (including primary and secondary residents). Assuming a constant ratio between primary and secondary residents, a future density of 5350 inhabitants per km² can be expected in 2030.

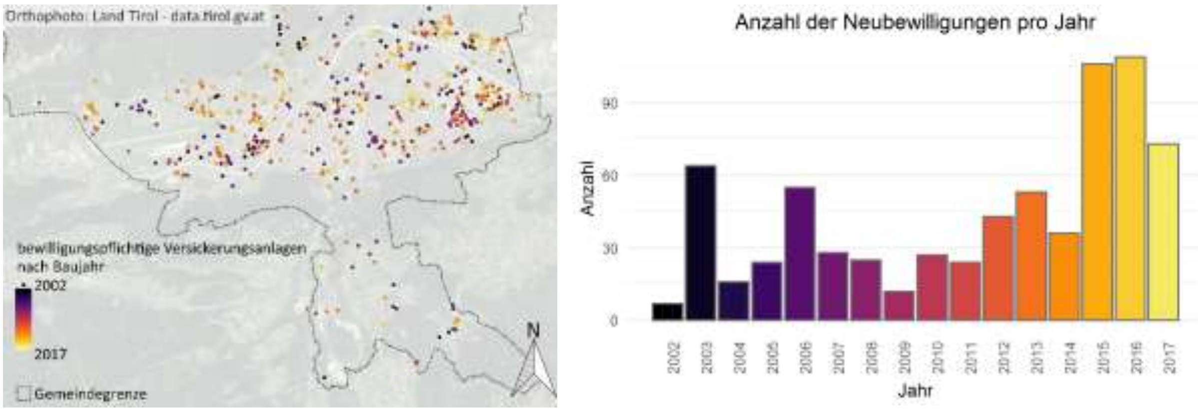
Innsbruck is blessed with a high amount of fresh water resources. According to ÖVGW (2018), only one third of the available water resources are demanded. Also, the city's wastewater treatment plant has still capacities, as it was built in times when bigger industrial companies were located in Innsbruck, supplying the wastewater treatment plant with highly loaded and thus very nutritious wastewater. Meanwhile, these companies moved away. As a result, the municipalities administration is not pressurised by any water issues of supply, drainage or treatment. Urban water management plays therefore only a minor role for spatial planners. They are more focused on the housing problems due to the city's persistent increase in popularity. Nevertheless, general objectives of urban drainage and stormwater management strategies are defined in the regional planning program.

The regional planning program is developed undisclosed to prevent land speculations. Consequently, also information exchange between specialist departments (e.g. the outsourced operator of the water infrastructure, the Innsbrucker Kommunalbetriebe AG) is restricted. Therefore, urban drainage specialist can only give general guidance during the planning process or specific impetus in the aftermath. An accompanying cooperation is thus not present in this case study.

Status quo of the urban drainage infrastructure

A general obligation to connect any stormwater runoffs to the city's combined sewer system was present until the turn of the millennium. Then, a new law (TiKG, 2000) became effective in the year 2001 and almost all incurring surface runoffs from stormwater have to be infiltrated on the own property. Accordingly, the operator of the urban drainage system is still obligated to drain the precipitation runoffs from all buildings connected prior to the commencement of this new law. Anyway, surface runoff from traffic areas is still preferred to be drained into the sewer system.

A Water Information System (WIS) for the federal state of Tyrol (www.tirol.gv.at/umwelt/wasser/wis) is publicly available. Amongst others, it contains a database containing all water related issues which are subject to approval according to the Water Rights Act (WRG, 1959). This database allows doing a stock analysis of all stormwater infiltration systems, which are subject to approval (Figure 11).



a) b)

Figure 11. Stormwater infiltration systems, which are subject to approval according to their construction year since 2002 (a) within the main settlement area of Innsbruck and (b) the number of new approvals per year.

In total, since 2002 approximately 700 new systems were approved. About half of them were approved in the last 4 years (since 2014). The exact amount of stormwater infiltration systems is not quantifiable, as e.g. the drainage of roofs up to an area of 2500m² or the drainage of cyclist and pedestrian paths are insignificant and are thus not subject to approval (Amt der Tiroler Landesregierung, 2016).

This analysis does not allow drawing a conclusion about whether there are areas with a certain time period of approving particularly many new systems (e.g. kind of a construction boom of stormwater infiltration systems).

Existing sewer infrastructures

Restructuring and densifications as favoured in the ÖROKO 2.0 will mainly be executed as a reconstruction of existing buildings. Often, this is accompanied by an adaptation of existing drainage infrastructures to a more contemporary state of the art. Such measures will be subject to compliance with the stated objective of at least preserving, if not even increasing the available green spaces. This might further have positive impacts on the existing (mainly grey) drainage infrastructure. At least, no increase in precipitation runoff of already developed areas has to be expected. Hence, the following investigations are restricted to structural development areas on currently empty fields.

To get an idea of which effects the designated expansion zones might have on the urban drainage system due to the resulting increase of surface sealing, a heuristic approach is chosen. The hydrodynamic model of Innsbruck serves as a basis for this approach. This model has been used and described several times in other studies on this case study (Mikovits et al. 2017; Möderl et al. 2015; Tscheikner-Gratl et al. 2016).

According to the surface balance given in the ÖROKO 2.0, theoretically the future demand of empty space amounts to 29-35ha for the creation of housing facilities and 13-20ha for commercial usage, already including compaction measures.

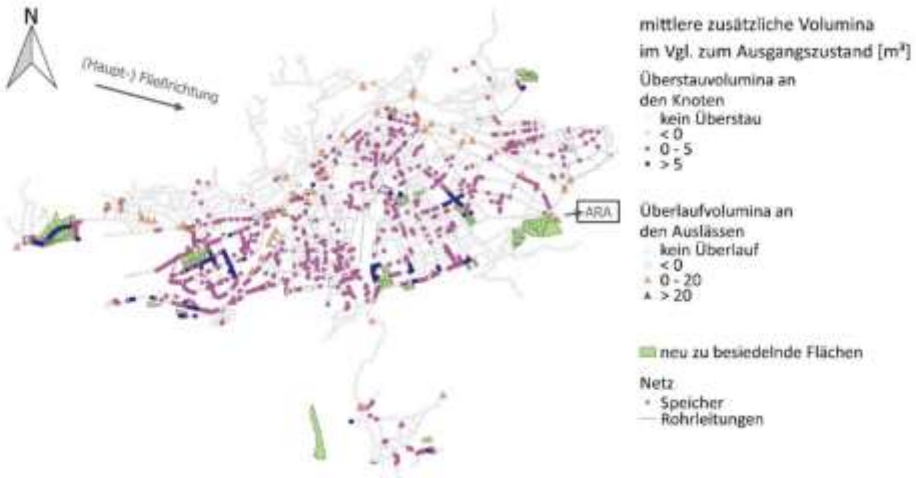


Figure 12. Absolute differences in flooding and surcharging volumes due to newly developed areas compared to status quo (simulated with a design storm of Euler II, rp=5y; average values of 100 scenarios).

As the real distribution of these 42-55ha in total is unknown, they are spread randomly on predominantly empty structural development areas and included to the hydrodynamic model in 100 different scenarios. By this, 100 different possibilities of increased surface sealing can be investigated. For subsequent hydrodynamic simulations, the software SWMM (Gironás et al. 2010) is used. Subcatchment imperviousness is assigned according to Gujer (2007) with 70% for housing areas with steep roofs and 75% for town centres. Two design storms of Euler Type II (ÖWAV RB11, 2009) with return periods (rp) of rp=5y and rp=10y are used for simulations. These rain events have a duration of 180 minutes each and a peak intensity of 10.2mm/min (rp=5y) and 12.0mm/min (rp=10y). These assumptions represent worst-case scenarios, where against the obligation to infiltrate stormwater, all surfaces of new buildings drain directly into the sewer system.

For dimensioning of sewers within city centres, industrial and commercial areas, a return period of rp=5y is recommended in Austria. The following figures show therefore only the evaluations of simulations with the design storm with a return period of 5 years. Results for rp=10y are similar, they differ only quantitatively but not qualitatively.

Especially in areas with generally high flooding expected flooding volumes, an increased risk due to the new developed areas can be seen in Figure 12. In average, the simulated 100 scenarios result in an increase of +5m³ flooding volume per node at several nodes in these areas. Additionally, the catchment connection near the airport shows to have a significant impact on the risk assessment of this analysis. Even though only small amounts of flooding volumes have to be expected (< 10m³ per node in average), compared to the status quo, this is a great increase (up to +24m³).

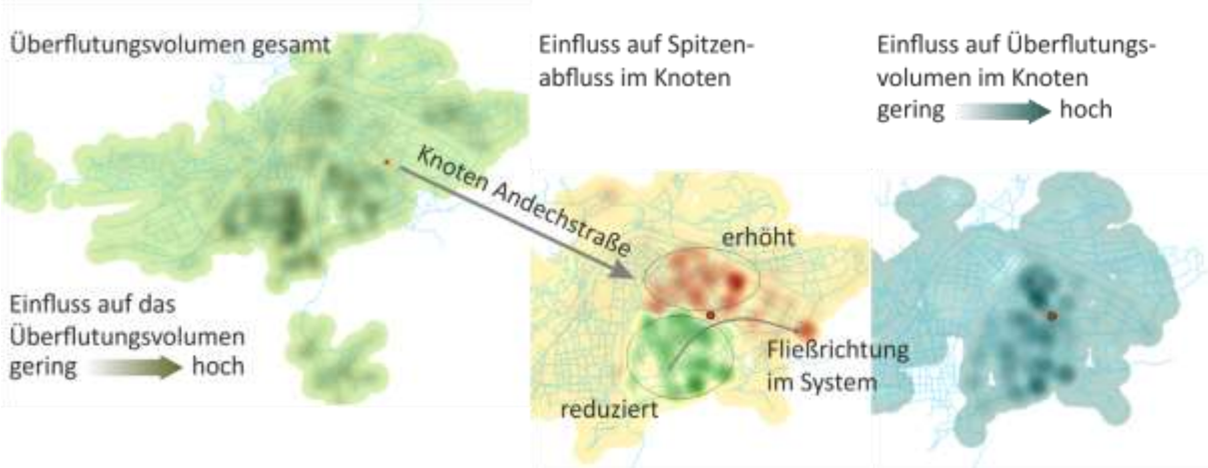
This analysis further results in increased surcharge volumes of combined sewer overflows into the river Inn from about the estuary of the river Sill and downstream, mainly southern (coming from the city centre, Pradl and Saggen). A design storm event with rp=5y results in approximately +3000m³ more inflow to the wastewater treatment plant in average of the 100 evaluated scenarios (status quo is approximately 80000m³).

Urban development as "black box" for drainage planning

Planners of the ÖROKO 2.0 were working secretly until a draft of the program was released to public. On the one hand, this brings the advantage of preventing land speculations. On the other hand, this modus operandi restricts the interference of specialists of different disciplines. After the publication of the spatial program, different disciplines are presented with a fait accompli regarding the future land use.

For urban drainage management, there are different possibilities to provide informative input to the spatial planners even without knowing their plans, i.e. a one-way flow of information. These include e.g. water balance models (Henrichs et al. 2016; Rauch 2013; Zeisl et al. 2018) or sensitivity maps. By this, aspects of urban drainage planning can be included into the considerations of spatial planners early enough while still keeping the creation of a spatial program secret. For the existing urban drainage system of Innsbruck, Figure 13 shows such a map. The ratio between certain simulation results and their initial values when altering subcatchment parameters is depicted. Simulations are again done with the software SWMM (Gironás et al. 2010). On the one hand, the impact of increased surface sealing or area detachment on specific system-wide parameters (e.g. total flooding or combined sewer overflow volume) or on results in specific nodes (e.g. peak flows, flooding volumes) can be evaluated.

For the evaluation of flooding volumes, the model is simulated with the same design storm of Euler II (rp=5y) as already used previously for the random scenarios. For evaluations of combined sewer overflow volumes (Figure 14), the rain input a 1-year measurement series from a measurement campaign in 2012 is used for simulation, as not only heavy rain events but also less intense but longer rain events are relevant for combined sewer overflows.



(a) (b) (c)

Figure 13. Effects of area disconnection (simulated with a design storm) (a) on the total flooding volume, (b) on the peak flow in the depicted node, (c) on the flooding volume of the depicted node.

For example, it can be seen that about 66% of the total combined overflow volume leaves the system through only 2 of 36 overflow structures. Figure 14c) and d) show, where a decrease of surface sealing seems to influence combined sewer overflow emissions most. The overlap of these results with the designated structural development areas of the ÖROKO 2.0 shows that these designated areas are not located in highly efficient zones for area detachment. Therefore, no high impact has to be expected due to these newly developed areas.

(a) (b) (c) (d)

Figure 14. Sensitivity of existing catchments: (a) impacts of unsealing the respective areas and (b) impacts of +30% densification on total combined sewer overflow emissions. Main areas of influence for the two crucial combined sewer overflows (MÜ): (c) MÜ 13 – primary discharge for the densely populated city centre of Innsbruck; (d) MÜ 22 – discharge for the area north of the river Inn.

The analysis of the new regional spatial planning program, which is still in process, show that decision-makers are familiar with issues of future sustainable stormwater management. Nevertheless, a dialogue with specific qualified personnel is missing during the planning phase. This delimitation origins mainly in the prevention of land speculations. Due to Innsbruck’s location in the middle of the Alps, space availability is very limited and land prices exert pressure in many ways. Compared to this problem, the generous presence of water resources and water infrastructures does not stress urban water management at all.

With information about the future development of Innsbruck, hydrodynamic simulations in this study did not prove significant increases of risks because of additional loads on the existing drainage system. To provide beneficial information about the impacts of altering surface structures on flooding risks and water quality already during the planning process of the regional spatial planning program, sensitivity maps of already connected areas seem to be a helpful tool. Spatial planners can thus refer to information e.g. about where the consideration of additional green spaces would be most efficient to ensure a safe discharge of stormwater and combined wastewater to the wastewater treatment plant. Similarly, these evaluations can be used to identify areas with an increased necessity to persuade landowners to detach their property from the public sewers and consider alternative stormwater treatment, e.g. on-site infiltration. As spatial planners and decision makers are already familiar with the general concepts of sustainable and future oriented stormwater management, convincing landowners and consequently implementation is the last step for the present case study.

These results have been published in Vonach, T., et al. A Heuristic Method for Measurement Site Selection in Sewer Systems. Water, 2018. 10(2) [1] and in Vonach, T., et al. How to choose from the cornucopia of possibilities in calibration data estimation. Water Resources Management, 2018 [2]

Evantually we set the focus on the consequences of decentralised stormwater systems and blue-green infrastructure on urban microclimatic and bioclimatic conditions. Primarily designed to decouple rainwater and reduce pressure from the urban drainage system (Butler and Parkinson, 1997; Woods-Ballard et al., 2007; Torgersen et al., 2014; Mikovits et al., 2017 and Goncalves et al., 2018), decentralised stormwater systems generate multi-benefits by offering infiltration, evapotranspiration and storage capabilities. Including, to a large extent, identical techniques (Fletcher et al., 2014), blue-green infrastructure and decentralised stormwater systems contribute to a reduction of sealed surfaces, consequently enhancing vegetated areas in the cities (Coutts et al., 2013; Gago et al., 2013 and Hansen et al., 2019). These effects result in a reduction of urban heating, mitigate the UHI effect and improve bioclimatic conditions (EPA, 2008; Foster et al., 2011; Coutts et al., 2012; Jones and Somper, 2013; and Stangl et al., 2019). Recent developments emphasise on the planning support for long-term strategies, identifying priority areas for decentralised stormwater systems to maximise multi-functionality (Kuller et al., 2017; Zhang and Chui, 2018; Kuller et al., 2019; Zischg et al., 2019 and Bach et al., 2020). To cope with the challenges climate change poses, the city of Innsbruck started putting focus on implementing adaptation measures such as blue-green infrastructure or decentralised stormwater systems. To prepare for future challenges, the city of Innsbruck is currently working on long-term strategies to improve climatic conditions across different urban structures.

Effects of changing surface characteristics on urban microclimatic and bioclimatic conditions

To be able to assess consequences of changing surface characteristics on the urban microclimate, we introduce a simple and fast spatial modelling approach to carry out fine-scale simulations for land surface temperature (LST), mean radiant temperature (MRT) and Universal Thermal Climate Index (UTCI) by leveraging the available accuracy from remote sensing data and the capabilities of Geographic Information System (GIS) software in a 2D environment. With this modelling approach, we want to emphasise the influence that changing surface characteristics and associated surface temperatures have on bioclimatic conditions and urban heating. The modelling approach is based on a fine-scale surface classification embedding important surface characteristics, combined with the approach from Matzarakis et al. (2010) and Bröde et al. (2010) including essential environmental and meteorological parameters. Simulations are carried out in a 2D environment offering the opportunity for spatio-temporal evaluation of LST, MRT and UTCI distribution across different city scales. This has never been explored explicitly before. Capabilities of the modelling approach have been demonstrated in evaluating variable urban structure types and their potential and constraints for decentralised stormwater management based on Simperler et al. (2018)'s typology classes for Innsbruck (see Figure 15). These urban structures comprise different quantities of sealed and vegetated surface types, building shapes, orientation and height. Overall, comparison of the results with reports from the scientific literature shows a good agreement of LST, MRT and UTCI values and distributions for different land surface types as well as diurnal variations. The methodology and results can be found in the peer-reviewed paper: *Back, Y., et al. (2020): A rapid fine-scale approach to modelling urban bioclimatic conditions* in the journal Science of the Total Environment.

Within the studies we emphasised on two important parameters for LST, MRT and UTCI calculations. These are: Emissivity (ε) and Bowen Ratio (B_o). An increase of ε values describes the difference from a brighter to a darker coloured surface. An increase of B_o values describes the difference from a porous wet vegetated surface to a sealed surface. In general, lower ε and B_o values lead to lower LST and lower B_o values lead to lower MRT and UTCI. However, lower ε values lead to an increase of MRT and UTCI. This effect is already known but must be given more attention as high-albedo surfaces are a common strategy for urban heat mitigation. Introducing decentralised stormwater systems or blue-green infrastructure has a major impact on B_o values. Urban forms with a higher degree of surface sealing show higher B_o values. Therefore, changing these surfaces from sealed to porous, vegetated surfaces, lowers LST and consequently MRT and UTCI values.

The approach shows good capabilities of assessing urban thermal comfort fast across different city scales and is capable of supporting urban planning processes for heat mitigation. Significant potential in applying the modelling approach to identify priority areas for adaptation measures and to maximise the multifunctionality of heat mitigation solutions such as blue-green infrastructure in urban areas can be seen.

These results have been published in Back, Y., et al. A rapid fine-scale approach to modelling urban bioclimatic conditions. Science of the Total Environment, 2020. [10]

Removing barriers and improving resilience (WP 5)

Decentralised stormwater management systems are state of the art tools to improve liveability in cities and adapt to the challenges climate change poses. This statement is valid within the scientific community but has also reached political levels and decision-makers.

Following barriers in implementing blue-green infrastructure systems have been identified:

- The space requirement of blue-green infrastructure is higher compared to conventional (grey) infrastructure,
- more complex organization caused by the involvement of different stakeholder groups during planning, implementation and maintenance phase,
- unclear long-time technical performance related to unclear lifetime of NBS systems,
- unclear water treatment performance especially for polluted surface runoff (e.g. de-icing fluids during winter time) and
- adaptation needs are often not seen for existing systems and changing climate is not considered in technical guidelines and documents for the design.

In close contact with different stakeholder groups (city council, sewer system operator) in this project, different procedures to reduce barriers have been introduced, mainly aiming to implement a long-term adaptation strategy. To be able to cope with future challenges, long-term strategies need to be implemented into the cities' development plans. Determining future land use designations and development areas, these plans are a powerful tool and contemporaneous influence and support adaptation measures. However, communication between the different parties is lacking vital information exchange.

The analysis of the new regional spatial planning program, which is still in process, shows that decision-makers are familiar with issues of future sustainable stormwater management. Nevertheless, a dialogue with specific qualified personnel is missing during the planning phase. This delimitation origins mainly in the prevention of land speculations. Due to Innsbruck's location in the middle of the Alps, space availability is very limited and land prices exert pressure in many ways.

As the city council is currently working on a climate change adaptation strategy plan, our project and results were of great interest and the project CONQUAD was used to generate products in order to reduce barriers in the implementation of NBS systems for climate change adaptation. The idea was to develop products, which can be used in an internal decision-making process of the spatial planning of the city. In this way, it is not necessary for the spatial planning department to share confidential material at early stages of the planning process.

We have introduced a rapid fine-scale approach to modelling LST, MRT and UTCI values for different urban forms. The approach is replicable and applicable in any urban environment from a small municipality to a big city, with respect to their geographic locations and climatic conditions. The approach and its results can be used to identify priority areas for adaptation measures on different scales throughout the cities and can serve as a tool for urban planners as well as for the implication of effective policy suggestions.

At the regional scale, the surface classification used in the above mentioned approach, covered with a 50m x 50m grid, can be used to identify areas with higher degree of sealed surfaces, an example of which is illustrated in Figure 15. By extracting single areas with different degrees of surface sealing (Example 1-3 in Figure 15), a correlation with certain urban forms can be detected. Having detected hot spots of sealed surfaces at the regional scale (in Figure 15 an area representing the structure type SHOP - Office administration trade and commerce was chosen), further in-depth analyses at the local scale and microscale are possible for different time steps, using the above mentioned approach to modelling LST, MRT and UTCI values. Due to high accuracy in the output datasets, it is possible to analyse e.g., occurrence, shape and vegetation health status of green roofs and detect suitable locations at the local scale and the microscale.

Areas of urban thermal discomfort can be detected and suggestions for adaptation measures can be made. To enhance synergies and multiple benefits from implementing decentralised stormwater systems and blue-green infrastructure to cope with the challenges that climate change poses, we suggest combining our approach and results with approaches from different fields. For example: By combining our approach with the differentiation of urban structure types and their potential and constraints for decentralised stormwater management (e.g. Simperler et al., 2018), placement of specific decentralised stormwater techniques, offering infiltration, evapotranspiration and storage capabilities among many other ecosystem services (Kuller et al., 2017), could be optimised to mitigate urban heat and reduce pressure on the urban drainage system at the same time.

Results from our approach and from combinations with other approaches from different fields can be of high value for urban planners and for the implication of effective policy suggestions. Hence, our approach can contribute to achieve sustainable development goals (e.g. SDG 11 - Sustainable cities and communities) in the Agenda 2030 and other political objectives (UN, 2015 and Franco et al., 2019).

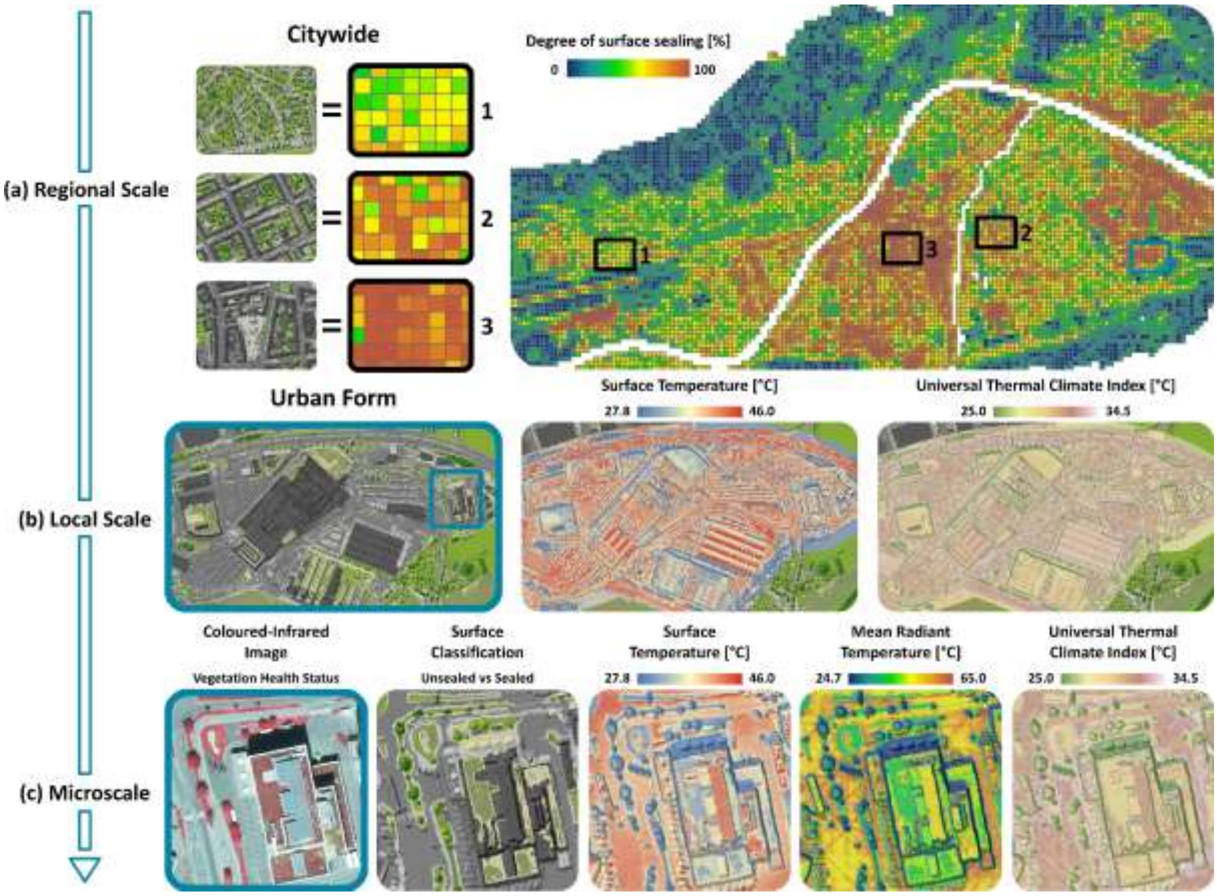


Figure 15. (a) - Citywide identification of hot spots of sealed surfaces, (b) - Local in-depth analysis modelling LST, MRT and UTCI for different time steps, (c) - Fine-scale study of the area of interest.

5 Conclusions

Both rainfall intensities and heat days increase due to climate change. These effects were quantified for the Alpine case study Innsbruck but are similar for other urban areas. We based the assessment of climate change effects on several RCP scenarios, global and regional climate models and results from the EURO-CORDEX and ReKliEs simulations. Changes of precipitation patterns was statistically downscaled based on statistical relations between different scales which are empirically derived from observations at rain gauges in the area. Starting from daily RCM data, empirical relations between daily and sub-daily data were used to find statistical distributions of sub-daily precipitation data, which are consistent with the daily values on the larger RCM scale. In summary, there is a **tendency to rarer but higher extremes**. Comparing the change signals of extreme precipitation in the emission scenarios RCP4.5 and RCP8.5, the mean change signals are insignificantly higher in the RCP 8.5 scenario, with a larger range among the models compared to the RCP4.5 scenario. Change signals are larger for extreme events with a longer duration above 90 min. A possible reason is the trend towards drier summers which has an effect on the occurrence of short-term convective precipitation events. However, the regional climate models do not capture all relevant processes of small-scale convective precipitation. While statistical downscaling can produce consistent data across scales, it cannot fully compensate for deficiencies in the regional climate model to simulate these events. Therefore, uncertainty regarding the short convective extreme precipitation events remain higher compared to larger events. The occurrence and intensity of rising temperatures and the frequency of excessive heat events per year depend on the location and the considered RCP scenario. As we did to estimate precipitation patterns, we used the ensemble of regional climate simulations from EURO-CORDEX/ReKliEs. Regarding the **number of days with a daily maximum temperature exceeding 30°C** reveals a relatively **small increase and little scenario differences until 2050** but a **strong increase in RCP8.5 based simulations towards the end of the century**.

Surface sealing driven by urbanisation and growing population increases pressure on the drainage system and flood risk. We analysed the impact of the current spatial planning program for Innsbruck, the ÖROKO 2.0 (approved by city council in 2019). **Hydrodynamic simulations in this study did not prove significant increase of risks because of additional loads on the existing drainage system,** mainly due to relatively short planning horizon of 10 years into the future. However, we suggest including sensitivity maps of already connected areas to provide beneficial information about the impacts of altering surface structures on flooding risks and water quality already during the planning process of the regional spatial planning program. Offering spatial planners to refer to additional information about where consideration of additional green spaces would be most efficient to ensure a safe discharge of stormwater and combined wastewater to the wastewater treatment plant. Similarly, these evaluations can be used to identify areas with an increased necessity to persuade landowners to detach their property from the public sewers and consider alternative stormwater treatment (e.g. on-site infiltration).

Decentralised stormwater management systems are state of the art tools to improve liveability in cities and adapt to the challenges climate change poses. Considered as climate change adaptation measures, these strategies (e.g. decentralised stormwater management systems, blue-green infrastructure, Nature-Based solutions, etc.) are able to reduce the pressure on the urban drainage system and simultaneously reduce urban heat, mitigate the UHI effect and improve human thermal comfort by leveraging synergies and enhancing multiple benefits. To use synergies and increase the multifunctionality of such strategies, a holistic view of the complex systems is required. For both urban drainage and urban temperature development, urban structure, urban form, degree of surface sealing and vegetation health status are essential and must be considered and analysed at different scales. To support proactive holistic planning, maps and tools should be developed to be able to consider the different aspects and boundary conditions. In order to assess consequences of changing surface characteristics on the urban micro- and bioclimatic conditions, we introduced a simple and fast spatial modelling approach to carry out fine-scale simulations for land surface temperature (LST), mean radiant temperature (MRT) and Universal Thermal Climate Index (UTCI) by leveraging the available accuracy from remote sensing data and the capabilities of Geographic Information System (GIS) software in a 2D environment. With this modelling approach, we emphasise the influence that changing surface characteristics and associated surface temperatures have on bioclimatic conditions and urban heating.

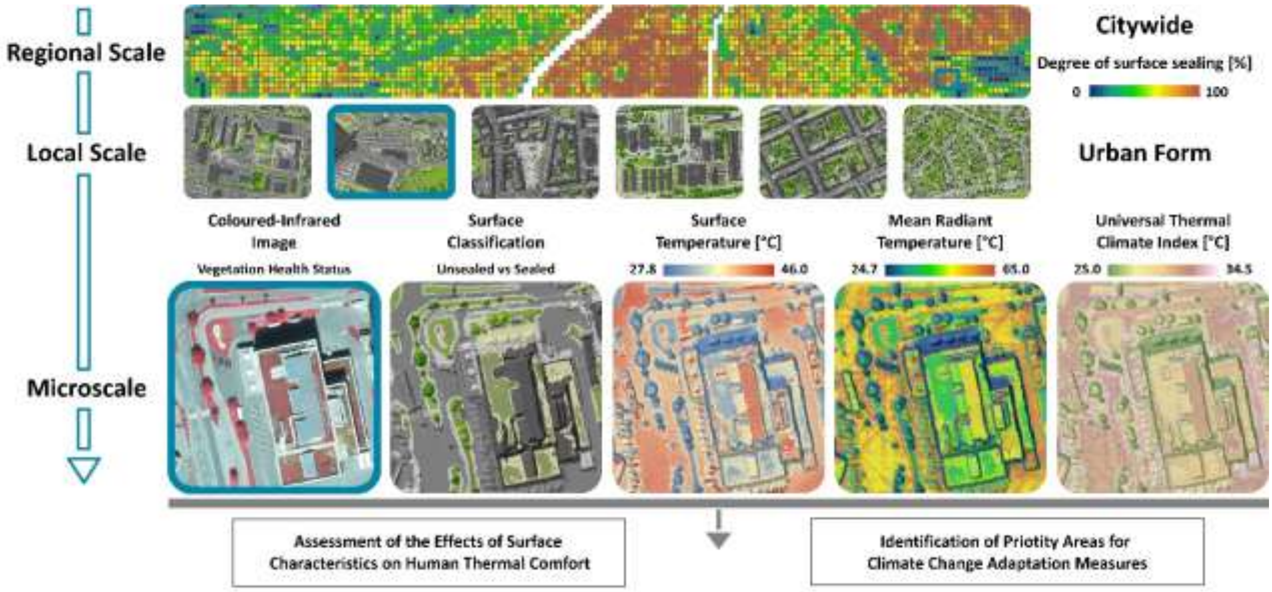


Figure 16. Identifying hot spots on a regional scale, locally analysing LST, MRT and UTCI and conducting fine-scale analysis of a specific area of interest.

Using the modelling approach, we are able to identify hot spots on a regional scale, locally analyse LST, MRT and UTCI for different time steps and conduct fine-scale analysis of a specific area of interest (see Figure 16). We used the model approach to conduct fine-scale analysis for six different urban structure types within the city of Innsbruck, enabling assessment of the effects of surface characteristics on human thermal comfort and identification of priority areas for climate change adaptation measures. Within these studies we concluded the following statements:

- **Contrasts between sealed and vegetated surfaces are reflected in surface temperatures,**
- **some urban typologies make up for the lack in vegetation by providing ample shading within their environment,**
- **distribution patterns and values of LST, MRT and UTCI across different structure types correlate with the appearance and frequency of specific surface classes,**
- **high-albedo surfaces decrease LST but increase the apparent temperature (MRT and UTCI values) effecting human thermal comfort and**
- **MRT and UTCI are more sensitive to changes in Emissivity values, whereas LST is more sensitive to changes in Bowen-Ratio values.**

Conclusions stated in the last two bullet points are depicted in Figure 17. These effects are already known but must be given more attention as high-albedo surfaces are a common strategy for urban heat mitigation. Introducing decentralised stormwater systems or blue-green infrastructure has a major impact on B_o values. Urban forms with a higher degree of surface sealing show higher B_o values. Therefore, changing these surfaces from sealed to porous, vegetated surfaces, lowers LST and consequently MRT and UTCI values.

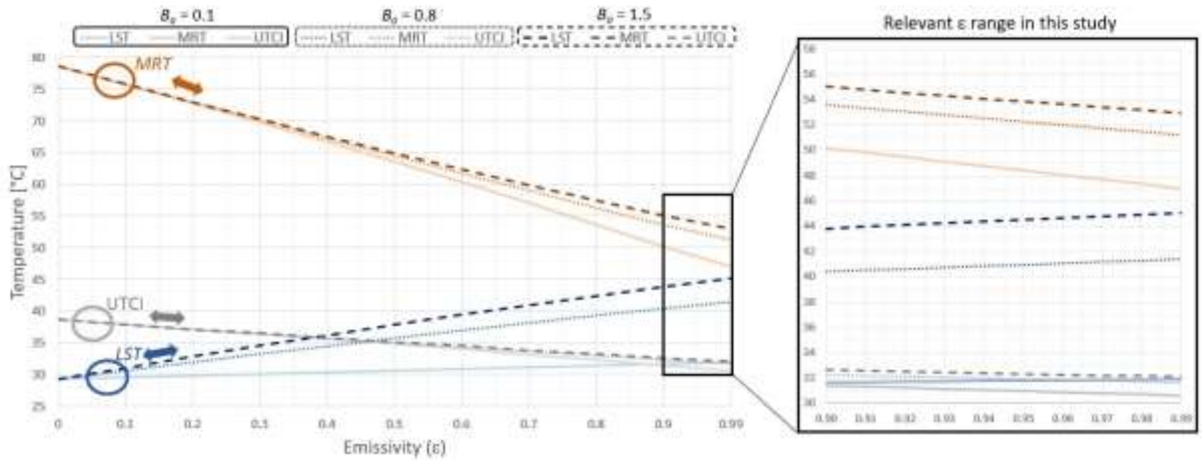


Figure 17. LST, MRT and UTCI values depending on Bowen-Ratio (B_o) and Emissivity (ε) values including a detailed extract of relevant ε range in this study.

We suggest to combine this approach and results with approaches to for example differentiate urban structure types and their potential and constraints for decentralised stormwater management (e.g. Simperler et al., 2018), to optimise placement of specific decentralised stormwater techniques, offering infiltration, evapotranspiration and storage capabilities among many other ecosystem services (Kuller et al., 2017), to simultaneously reduce urban heat, mitigate the UHI effect and reduce pressure on the urban drainage system.

The next or already ongoing steps are to hand over project results and generated GIS datasets on urban land use, identifying urban forms, surface temperature and universal thermal climate index to the city council for implementing the information in the city's climate change adaptation plan. At the same time two follow-up demonstration projects were derived, as it was shown that missing demonstration and "best-practice" projects are a significant barrier in implementing climate change adaption projects.

The project „cool-INN: Kühle urbane Lebensräume für eine resiliente Gesellschaft" including the project partners from the city of Innsbruck, Innsbrucker Kommunalbetriebe and the University of Innsbruck is already funded by the Austrian Climate and Energy Fund in the Smart Cities Demo - Living Urban Innovation 2019 program and started in spring 2020. This project aims on implementing urban cooling measures in a public space in Innsbruck, showing the cooling potential of blue-green infrastructure (see e.g. https://www.ibkinfo.at/projekt-cool-inn).

Another project proposal is currently being developed and aims to analyse the performance of blue-green infrastructure in treating pollutant stormwater runoff.

Cooperation during the project with stakeholders from the city of Innsbruck and Innsbrucker Kommunalbetriebe showed that the developed tools and data-sets are of high interest for different technical departments (spatial planning, underground infrastructure, water management, parks and green areas). We think that these results are of potential interest for other groups working in the large field of renaturing cities. The role of Nature-Based solutions, enhancing multi-benefits and ecosystem services, gains importance with future challenges posed by climate change. By this means, future collaborations with groups focusing on the improvement of biodiversity, air quality or sustainable communities is of high interest.

We also think that the developed workflow and models are of potential interest for other cities in Austria. The entire process is based on GIS data, which is usually available and can easily be replicated.

C) Project details

6 Methods

<u>Regional Climate Projections</u>

Within the EURO-CORDEX initiative, regional climate projections (RCMs) for impact research were produced by an international framework. EURO-CORDEX (www.euro-cordex.net) is part of the global Coordinated Regional Downscaling Experiment (CORDEX, http://wcrp-cordex.ipsl.jussieu.fr/; Giorgi et al. 2009). The regional simulations downscale the CMIP5 global climate projections (Taylor et al. 2012) based on scenarios of the representative concentration pathways (RCPs) (Moss et al. 2010; van Vuuren et al. 2011). Simulations are provided on standardised grids with two horizontal resolutions, 0.44° (EUR-44) and 0.11° (EUR-11). Table 3 gives an overview of the EURO-CORDEX simulations used in this study. The evaluated periods are the reference period (1971-2000) and the near future (2021-2050) under the RCP scenarios RCP4.5 and RCP8.5. The EUR-11 simulations shown in Table 3 with a horizontal resolution of 0.11° (approx. 12.5 km) and a temporal resolution of 1 day were used to study potential future trends of heavy and extreme precipitation.

Table 3. Regional climate simulations of EURO-CORDEX EUR-11 with the combinations of global climate models and regional climate models, and the denotation of the global realization (details at www.euro-cordex.net).

RCM / **GCM**	**RMIB-UGent-Alaro** (RMIB)	**CLMcom-CCLM4** (CLM-Community)	**DMI-HIRHAM5** (DMI)	**KNMI-RACMO22** (KNMI)
CERFACS-CNRM-CM5 (CERFACS)	*r1i1p1* *RCP4.5 & RCP8.5*			
ICHEC-EC-EARTH (SMHI)		*r12i1p1* *RCP4.5 & RCP8.5*	*r3i1p1* *RCP4.5 & RCP8.5*	*r1i1p1* *RCP4.5 & RCP8.5*
MOHC-HadGEM2-ES (MOHC)		*r1i1p1* *RCP4.5 & RCP8.5*		*r1i1p1* *RCP4.5 & RCP8.5*
MPI-M-MPI-ESM-LR (MPI)		*r1i1p1* *RCP4.5 & RCP8.5*		
NCC-NorESM1-M (NCC)			*r1i1p1* *RCP4.5 & RCP8.5*	

Within the German project ReKliEs (Regional Climate change Ensemble simulations for Germany), the EURO-CORDEX simulations were complemented by 12 dynamical simulations, as well as statistical simulations. These were produced using the RCP scenarios RCP2.6 ("mitigation") and RCP8.5 ("business as usual") and provided on the EURO-CORDEX grid EUR-11 with 0.11° horizontal resolution. The ReKliEs-domain covers Germany and the adjacent large river catchments draining into Germany, which include the region around Innsbruck, Tyrol. In addition, several climate indices (e.g. hot days, summer days, frost days) were provided for impact research. Indices defined via a fixed threshold are sensitive to model-specific biases. An 'implicit' bias-correction was conducted within ReKliEs to account for these biases, using individually adjusted thresholds for each model (Hübener et al., 2017, section 7.2). The individual thresholds were determined by comparing the frequency of threshold exceedances of model results and observations in the reference period. Simulations of the ReKliEs project (see Table 4) were considered for the evaluation of heat indices. Analysis was done for the near future (2021-2050) and the far future (2071-2100) compared to the reference period.

Table 4. EURO-CORDEX/ReKliEs simulations with the combinations of global and regional climate models, the attributing institutes and the RCP-scenarios (see www.euro-cordex.net and http://reklies.hlnug.de/home for details).

RCM GCM	**CLMcom-CCLM4** (CLM-Community)	**DMI-HIRHAM5** (DMI)	**KNMI-RACMO22** (KNMI)	**SMHI-RCA4** **(**SMHI**)**
CERFACS-CNRM-CM5 (CERFACS)	*r1i1p1* *RCP8.5*			*r1i1p1* *RCP8.5*
ICHEC-EC-EARTH (SMHI)	*r12i1p1* *RCP2.6 & RCP8.5*	*r3i1p1* *RCP2.6 & RCP8.5*	*r1i1p1* *RCP2.6 & RCP8.5*	*r12i1p1* *RCP2.6 & RCP8.5*
MOHC-HadGEM2-ES (MOHC)			*r1i1p1* *RCP2.6 & RCP8.5*	*r1i1p1* *RCP2.6 & RCP8.5*
MPI-M-MPI-ESM-LR (MPI)	*r1i1p1* *RCP2.6 & RCP8.5*			

Statistical downscaling of EURO-CORDEX RCM precipitation

A statistical downscaling procedure was conducted using the regional climate simulations of EURO-CORDEX in Table 3. The procedure is based on statistical relations between different scales which are empirically derived from observations. As observation database, highly resolved station data from ZAMG, ehyd and IKB stations of precipitation were used, supplemented by temperature observations from the HISTALP station data base. The gridded daily precipitation dataset EUR04M-APGD by MeteoSuisse (Isotta, 2013) was also used.

The statistical downscaling procedure was designed for the target to derive climate change signals of extreme sub-daily precipitation. It is described in Kleidorfer et al. (2015) and was developed further in order to process large datasets more efficiently and to apply it to ensembles of regional climate projections. The first step of the downscaling procedure is a two-dimensional bias-correction of the RCM daily precipitation and temperature data using a quantile mapping method. This is done after a regridding of the observed daily precipitation and temperature datasets to the regional climate model grid. ECDFs (empirical cumulative density functions) of simulated and observed quantities are compared in the reference period. Both the simulated and observed precipitation and temperature datasets are divided into a number of classes with fixed thresholds. Empirical transfer functions are derived to correct the data points in each precipitation-temperature-class. The transfer functions derived for the reference period are used to correct the future simulations in the same manner in dependency of the precipitation-temperature-class.

In a second step, starting from daily RCM data with a resolution of 0.11°, empirical relations between daily and sub-daily data are used to find statistical distributions of sub-daily precipitation data which are consistent with the daily values on the larger RCM scale. For this step, simulated days are compared to historical days in the observation dataset and from all days which are classified as 'similar', probability distribution functions of sub-daily precipitation are produced. The probability distribution functions of all days in a 30-year-period are merged to estimate the probability distribution function of the according duration over the whole period. This is repeated for different durations of precipitation between 10min and 12h and for every RCM realization.

From those probability distribution functions statistical extremes are derived in dependency of the duration and return period. The results are used to estimate climate change signals of extreme precipitation for the projection period in comparison to the reference period.

Regional climate scenarios for mean air temperatures and hot days per year

As a basis for impact assessment of future heat events, trends of mean air temperatures and heat indices were analysed. We consider the index 'hot days' (variable name: su30) which is the number of days per year with a daily maximum temperature $T_{max} >= 30°C$. This temperature threshold is relevant for impact research since the human body starts to suffer from increased heat stress above this threshold. The index is available from an ensemble of RCM simulations of EURO-CORDEX/ReKliEs (see Table 4 for a list of the considered GCM/RCM combinations and the contributing institutes). 30-year-averages of the index 'hot days' and the related temperature quantiles are calculated. Climate change signals are computed as relative changes of 30-year averages comparing the scenario results for the future periods 2021-2050 and 2071-2100 relative to the reference period 1970-2000.

Because of the scale difference between urban structures and the resolution of regional climate models, regional climate model output cannot directly be used for the simulation of urban microclimate. As a support tool to transfer the climate model results to input data for the simulation of bioclimatic conditions, selected samples from observations are used representing reference and future climatic conditions.

The records of two meteorological stations in Innsbruck are used as an input for the simulation of bioclimatic conditions including surface temperatures, mean radiant temperature and UTCI. The datasets with the parameters air temperature, air pressure, wind speed and cloud cover were provided by the ZAMG (Zentralanstalt für Meteorologie und Geodynamik, Innsbruck). Climate change signals are computed from the regional climate projections listed in Table 4 as statistical mean changes averaged over 6 model grid points around Innsbruck, Tyrol. This area comprises not only the Inn valley, but parts of the surrounding mountains with an averaged altitude above Innsbruck city situated at 574m.a.s.l. Consequently, the simulated mean and extreme temperatures are lower compared to Innsbruck stations and hot days (with a daily maximum air temperature >=30°C) occur less frequent.

In order to derive trends of hot days at the station level from the regional climate projections, several steps are conducted. First, climate change signals of the number of hot days are computed for the future periods 2021-2050 and 2071-2100 in relation to the reference period 1971-2000. Second, the exceedance probability of the 30°C threshold is related to the daily maximum air temperature at station level (T_{maxobs}), using histogram data of T_{maxobs} at the stations Innsbruck Airport and Innsbruck University. At the stations, the 30°C-threshold is exceeded approximately 10 days per year in average over the reference period, corresponding to the 97%-quantile of T_{maxobs}. With future temperatures increasing, the 97%-quantile of T_{max} will match a temperature above 30°C at the station level, T_{max}_Q97f. T_{max}_Q97f is estimated for the scenarios RCP2.6 and RCP8.5 under the assumption that the shape of the extreme tail of the probability distribution function (PDF) of daily maximum temperatures will not change in comparison to the observed PDF.

Starting with a day with a maximum air temperature of 30°C as reference day, days with maximum air temperatures reaching T_{max}_Q97f under the scenarios

RCP2.6 and RCP8.5 are selected from observations as future representatives.

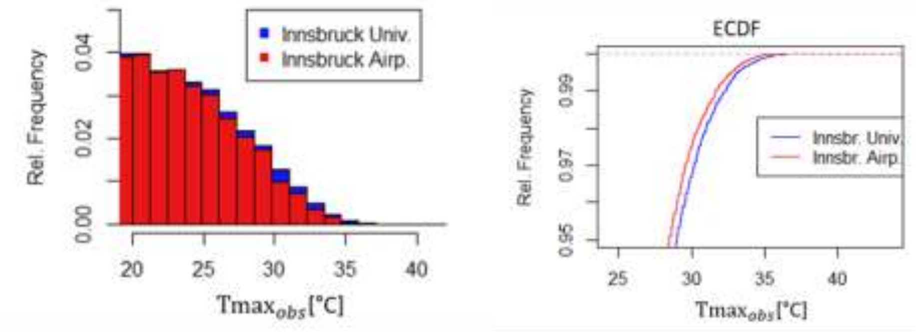


Figure 18. Histogram (left) and Empirical Cumulative Distribution Function (ECDF) of observed daily maximum temperatures (Tmax_{obs}) at the ZAMG meteorological stations Innsbruck University and Innsbruck Airport in the period 1971-2000. Sections show Tmax_{obs} above 20°C in the histogram and the highest 5% of Tmax_{obs} in the ECDF.

Hydrodynamic simulations using the software SWMM.

Hydrodynamic models were prepared with the software SWMM for the case study Innsbruck. A carefully built up and calibrated model is crucial for all further scenario analyses. The model has been updated with recent information about newly built structures and the latest surveys of the catchments. Then, model calibration has been investigated in several scenarios.

Surface classification of urban environments using GIS (Geographic Information System).

In the context of climate stress, urbanisation and population growth, design and planning tools that assist in decentralised and environmental infrastructural planning are becoming more common. In order to support the design of increasingly complex environmental and urban water infrastructure systems, current, accurate and easily obtainable spatial databases describing land cover types are crucial. Accordingly, a methodology categorising land covers that supplements these tools was proposed. Utilising a GIS (Geographic Information System) and imagery of high spatial accuracy obtainable from flyover techniques, radiometric and geometric data was generated to create a multi-functional classification of urban land cover, designed to be applicable to various decentralised urban planning tools. The methodology developed 13 individual land cover categories based on the capabilities of the utilised imagery, which are then adapted to suit planning tool requirements appropriately.

Introduction of a rapid fine-scale approach to modelling urban bioclimatic conditions.

Surface characteristics play a vital role in simulations for urban bioclimatic conditions. Changing relationships and distribution patterns of sealed and vegetated surfaces, building shapes, orientation and height across different scales in urban environments influence surface temperatures. Cities comprise different urban structure types which, depending on their surface characteristics, enhance the heating process, increasing the emergence of urban heat islands (UHIs). Detecting priority areas to introduce multi-beneficial climate change adaptation measures (green-blue infrastructure, decentralised stormwater systems) is set to be a key task for the cities long-term strategies to improve climatic conditions across different urban structures and scales. We introduced a simple and fast spatial modelling approach to carry out fine-scale simulations for land surface temperature (LST), mean radiant temperature (MRT) and Universal Thermal Climate Index (UTCI) in a 2D environment. Leveraging the available accuracy from remote sensing data and the capabilities of Geographic Information System (GIS) software, the modelling approach is based on a fine-scale land surface classification including important surface characteristics and essential environmental and meteorological parameters.

<u>Development of a Database and Web-GIS System for visualization of results</u>

To be able to share results and exchange knowledge as part of the end-user consultation (WP 1) the project results are available as GIS data and are published in a web GIS system. For this a database and visualization system has been developed.

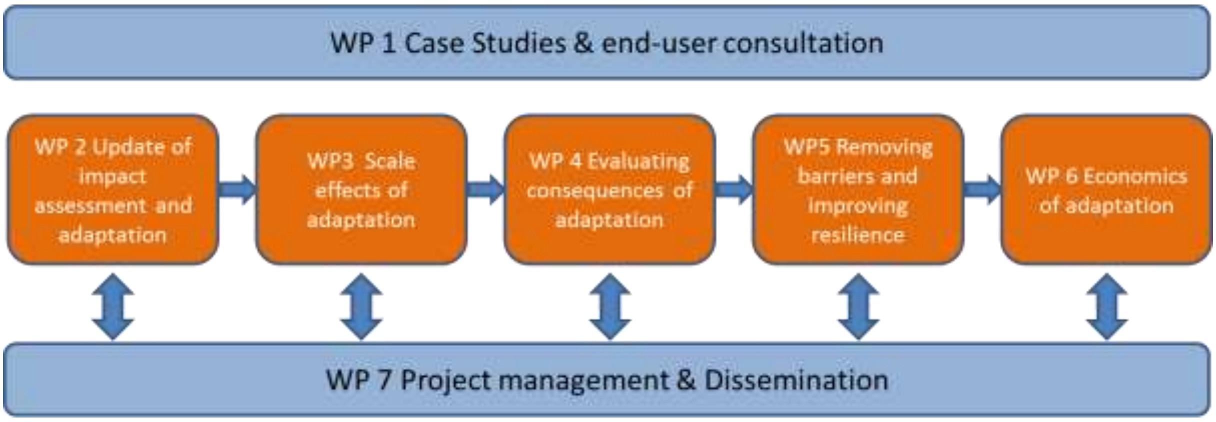
The operating system of the now docker based database system was updated from long-term support version Ubuntu Server 16.04 to Version 18.04 to Version 20.04. This version will get security updates until April 2025 – this way a save and low maintenance operation of the database and visualization system is possible beyond the end of the project. The database PostgreSQL / PostGIS version has been upgraded from version 9 to version 10, which supports the delivery of vector tiles as a native functionality. To be able to deliver also native raster data the last version is using version 11 with the needed build-in functionality. The data base system itself had been finished and enhanced, for better data safety (backup system), better security and access (REST-Interface) and an advanced user management with LDAP had been implemented. Based on this system the development of the web application (project visualization system) has started. An information platform for stakeholders like politicians, decision makers and city planners was needed. After the integration of a new Web-GIS in the project's visualization (QGISWebClient Version 2) a much better user interaction was made possible. This web GIS is very closely linked to the open source QGIS desktop application. With this system, it is possible to add map layers from the database system to the desktop GIS map, format them, add functions as printing templates, or object interactions and then export this GIS project to the web GIS world. The user of the web GIS has the same view of the generated maps as the editor on his desktop PC. This way allows a very fast and efficient transfer of scientific data and results to a selected audience or the public.

The QGISWebClient is a basic web GIS system with support for distance and area measure, free layer import for WMS sources, printing and many more functions.

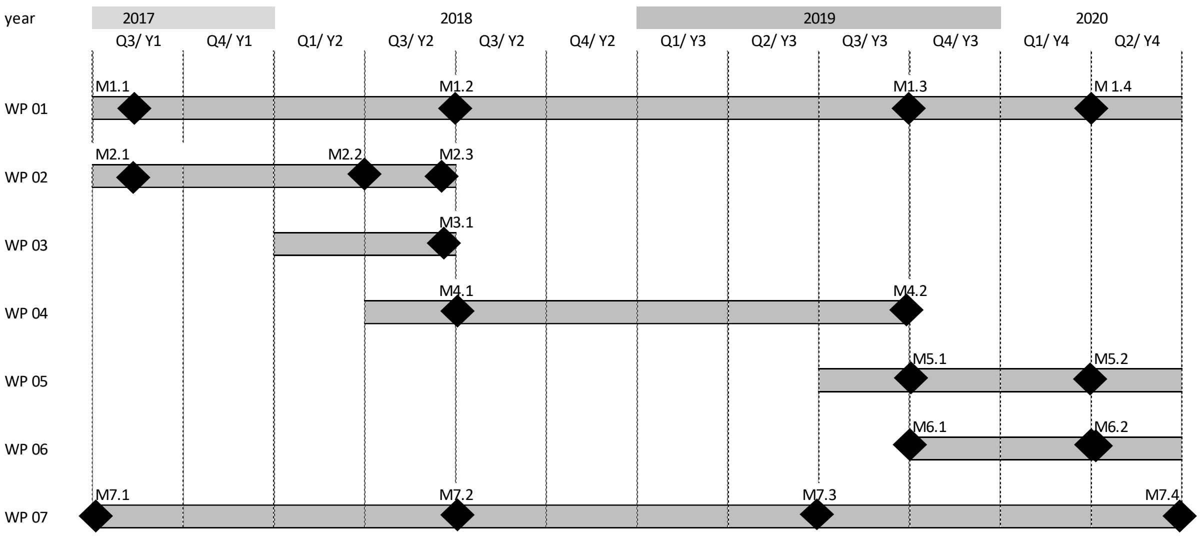
It is written in React and custom functions like interactive actions for map objects or specific user search options can be added easily. Currently with one project focus on microclimate simulation it is evaluated to support web-based 3D map representations. Due to growing problems and slow updates in the QGISWebClient project, in the last project phase a change to lizmap was made. Lizmap has the same functionality as QGISWebClient, but this open source software is developed and maintained by a French company (3Liz) and has much better support and update policies. Because ESRI's ArcGIS was introduced to the project, the connectivity was tested. The combination of ESRI desktop products and the open source-based system for vector data applications is working with no major problems. To support also the later added use of raster data a set of tools was developed to ensure interoperability. New visualization tools have been added for the Web-GIS. To visualize the urban environment and its impact on the microclimate, a 3D representation of the surrounding buildings is very helpful. As main library for this task, Mapbox GL JS was chosen. Mapbox GL JS is a browser-based JavaScript library. To render 3D data the WebGL library is used. With the implementation of this system, interactive three-dimensional maps can be presented over the world wide web. To allow a fast 3D data transfer, vector tiles are utilized. These vector tiles are small spatial bundled packets of geographic information. Unlike WMS, not raster but vector information is sent to the browser-based map system. This includes 3D data like the city's buildings. Due to a shift in the project focus, no 3D data is created, so the visualization has changed from 3D to handle multiple and large raster datasets in Web-GIS. The result of this work is an integrated information platform and visualization system for the stakeholders of the project.

7 Work and time plan

The project was organized in 7 work packages (WPs):



The project started 1st July 2017 and was planned for 36 months but extended by 2 months due to global COVID-19 pandemic and ended 31 August 2020.



8 Publications and Dissemination

<u>Publications</u>

1. Vonach, T., et al., A Heuristic Method for Measurement Site Selection in Sewer Systems. Water, 2018. 10(2).
2. Vonach, T., et al., How to choose from the cornucopia of possibilities in calibration data estimation. Water Resources Management, 2018.
3. Kleidorfer, M., et al., What can we learn from a 500-year event? – Experiences from urban drainage in Austria. Water Science & Technology, 2018.
4. Mikovits, C., W. Rauch, and M. Kleidorfer, Importance of scenario analysis in urban development for urban water infrastructure planning and management. Computers, Environment and Urban Systems, 2017.
5. Mikovits, C., et al., Decision Support for Adaptation Planning of Urban Drainage Systems. Journal of Water Resources Planning and Management, 2017. 143(12).
6. Vonach, Tanja; Einfalt, Thomas; Rauch, Wolfgang; Kleidorfer, Manfred (2019): Rain Gauge vs. Radar Measurements - Modelling an Extreme Rain Event with High Spatial Variability. In: Green Energy and Technology New Trends in Urban Drainage Modelling. UDM 2018, S. 413 - 418.
7. Back, Yannick; Zischg, Jonatan; Bremer, Magnus; Rutzinger, Martin; Kleidorfer, Manfred (2019): Einsatzmöglichkeiten von Geoinformationssystemen in der Siedlungswasserwirtschaft am Beispiel Einbindung dezentraler Entwässerungssysteme zur Entlastung des städtischen Abwassernetzes. In: Österreichische Wasser- und Abfallwirtschaft.
8. Back, Yannick; Kleidorfer, Manfred; Rauch, Wolfgang (2020): Dezentrale Regenwasserbehandlung zur Entlastung der Kanalisation und Minderung urbaner Hitzeinseln. In: Österreichische Ingenieur- und Architekten-Zeitschrift 164, S. 202 - 207.
9. Oscar Hiscock; Yannick Back; Manfred Kleidorfer; Christian Urich: A GIS-based land cover classification approach suitable for fine-scale urban water management, under review in Water Resources Management.
10. Yannick Back, Peter Marcus Back, Alrun Jasper-Tönnies, Wolfgang Rauch and Manfred Kleidorfer (in press): A rapid fine-scale approach to modelling urban bioclimatic conditions, Science of the Total Environment, https://doi.org/10.1016/j.scitotenv.2020.143732

Conference presentations (presentation + proceeding)

1. Kleidorfer, M., et al. What can we learn from a 500-year event? – Experiences from urban drainage in Austria. in 14th International Conference on Urban Drainage (ICUD 2017). 2017. Prague (Czech Republic): Den Haag: International Water Association.
2. Vonach, T., et al., Die neue Raumordnung in Innsbruck - Herausforderungen und Chancen für die Siedlungswasserwirtschaft, in Aqua Urbanica, T.G. Schmitt, Editor. 2018, Institut Wasser Infrastruktur Ressourcen: Landau i.d. Pfalz.
3. Vonach, T., et al. Sensor placement for hydrodynamic model calibration. in 14th International Conference on Urban Drainage (ICUD 2017). 2017. Prague (Czech Republic): Den Haag: International Water Association.
4. Vonach, T., et al. Messstellenauswahl für die Kalibrierung hydrodynamischer Modelle am Fallbeispiel Telfs. in Aqua Urbanica 2017. 2017. Graz, Austria: Verlag der Technischen Universität Graz.
5. Back, Yannick; Kitanovic, Stefan; Urich, Christian; Kleidorfer, Manfred (2019): Untersuchung und Optimierung der Einbindung dezentraler Entwässerungssysteme zur Entlastung des städtischen Abwassernetzes und Minderung urbaner Hitzeinseln. In: Burkhardt, Michael; Graf, Christian: Tagungsband Aqua Urbanica 2019. Regenwasser weiterdenken - Bemessen trifft Gestalten. 9.- 10. September 2019, RigiKaltbad (Schweiz). Rapperswil: HSR Hochschule für Technik Rapperswil., S. 9 - 15.
6. Back, Yannick; Urich, Christian; Kitanovic, Stefan; Kleidorfer, Manfred (2019): Implementing different decentralized stormwater techniques to reduce pressure on the urban drainage system and mitigate the urban heat island effect. In:Bertrand-Krajewski, Jean-Luc; Fletcher, Tim D.: 10th International Conference on Urban Water, Planning and technologies for sustainable management (NOVATECH 2019). Abstract Compendium. 01-04 July 2019, Villeurbanne Cedex. Lyon: Graie., S. 330.
7. Alrun Jasper-Tönnies, Yannick Back, Peter Bach, Wolfgang Rauch, Thomas Einfalt, and Manfred Kleidorfer (2020): Reduktion von Hitzestress und Überflutungen im urbanen Raum durch Nutzung von Synergien bei Anpassungsmaßnahmen an den Klimawandel
8. Jasper-Tönnies, A., Back, Y., Bach, P., Rauch, W., Einfalt, T., and Kleidorfer, M.: Reduktion von Hitzestress und Überflutungen im urbanen Raum durch Nutzung von Synergien bei Anpassungsmaßnahmen an den Klimawandel, 12. Deutsche Klimatagung, online, 15 March–18 Mar 2021, DKT-12-19, 2020

Poster

1. Vonach, T. & Kleidorfer M. (2017): CONQUAD - Konsequenzen der Adaptierung von Entwässerungssystemen, 18. Österreichischer Klimatag, Wien
2. Vonach, T. & Kleidorfer M. (2017): CONQUAD - Konsequenzen der Adaptierung von Entwässerungssystemen, Österreichische Wasserwirtschaftstagung 2017, Linz
3. Back, Yannick & Kleidorfer Manfred (2019): CONQUAD – Consequences of Adaptation of Urban Drainage Systems, 20. Österreichischer Klimatag, Wien.

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