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### ► **To cite this version:**

Yannick Back, Alrun Jasper-Tönnies, Georg Leitinger, Thomas Einfalt, Inga Ferk, et al. More blue along the green infrastructure to improve drought resilience in Alpine cities. Novatech 2023 11e Conférence internationale sur l'eau dans la ville, Jul 2023, Lyon, France. <hal-04184757>

**HAL Id: hal-04184757**

**<https://hal.science/hal-04184757v1>**

Submitted on 22 Aug 2023

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## More blue along the green infrastructure to improve drought resilience in Alpine cities

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### RÉSUMÉ

### ABSTRACT

Water management in Alpine cities is under huge pressure from climate change including altered temperature and precipitation patterns, which demand adaptation measures such as Blue-Green Infrastructure. A combination of nature-based and technical solutions can help to improve both the water and energy balance, increase the evaporative cooling effect driven by water availability, decrease peak runoff and, thus, reduce urban heat and flood hazards. The interdisciplinary project BlueGreenCities builds upon current research and integrates ecological and technical disciplines to close knowledge gaps regarding (1) land-atmosphere interactions within ecological, hydrological, and meteorological systems and (2) the performance of Blue-Green adaptation measures under different climate scenarios in Alpine urban areas. The project thereby supports scientists as well as city planners, land developers, and political stakeholders in decision-making for sustainable and flexible water management systems that maintain human wellbeing, economic development and the protection of the living environment. First results present the effects of the 2019 European summer drought on vegetation health and evaporative cooling potential, indicating that decreasing water availability diminishes capabilities of urban green spaces to maintain an evaporative cooling effect if not irrigated extensively. This highlights the importance of urban water management to increase cities' resilience towards prolonged dry periods and water scarcity.

### KEYWORDS

Blue-Green Infrastructure, Climate Change Adaptation, Environmental Modelling, Interdisciplinary, Water Availability

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## 1 INTRODUCTION

Widespread land cover alteration due to anthropogenic activities modifies land surface properties in absorbing, reflecting, and emitting radiation as well as in infiltrating, evaporating, and storing water (Mahmood et al., 2014). This consequently changes surface energy and water fluxes and, thus, microclimatic conditions (Seneviratne et al., 2010). Progressive surface sealing results in higher runoff rates, less groundwater recharge, inhibited diurnal evaporative cooling and increased substrate heat storage, leading to augmented heat exchange by convection and, consequently, to an intensification of urban heat (Oke et al., 2017). Evapotranspiration represents a primary process for energy and water exchange between the hydrosphere, atmosphere and biosphere, thus, the main determinants of the warming effect in cities lie in differences between evapotranspiration and convection efficiency between urban and rural areas (Manoli et al., 2019). With climate change altering local temperature and precipitation patterns, increasing the occurrence of dry periods and frequency of excessive heat events, extreme precipitation events as well as tropical nights per year (Fischer et al., 2021, Arnbjerg-Nielsen et al., 2013), urban water management is becoming increasingly relevant. Considering an intensifying global water cycle and resulting decrease in water availability amplified by land-atmosphere feedbacks (Berg et al., 2016), spatio-temporal variability in water availability and its impact on promoted urban green infrastructure for heat mitigation is insufficiently represented in current studies. The project “Blue-Green Infrastructure for Improving Resilience to Floods and Droughts in Alpine Cities - BlueGreenCities” wants to build upon current knowledge and the latest findings to study the consequences of uncertain water availability and the resulting effects on adaptation measures such as Blue-Green Infrastructure, to improve our cities resilience under future climate change scenarios.

## 2 METHODOLOGY

The studies within the project are mainly conducted in the alpine city of Innsbruck, Austria, which has a humid continental climate with high annual and diurnal temperature differences and wet summer. However, the project also includes a focus on the transferability of results to other cities worldwide. During first investigations, we analysed the effects of the 2019 European summer drought on vegetation health and evaporative cooling potential, by means of vegetation water content (VWC) and potential evapotranspiration (PET) across the city of Innsbruck and within a specific case study area (AOI) in the city (Fig.1). VWC [kg/m<sup>2</sup>] was calculated using Eqn. 1, which is based on the approach after Chan et al. (2013), comprising two terms calculating (1) foliage water content and (2) stem water content, using the NDVI (Normalised Difference vegetation Index) and a stem factor. The NDVI was calculated from CIR (coloured infrared)-images (provided by the local government *Land Tirol*) with a spatial resolution of 0.2 m.

$$VWC = \underbrace{1.9134 * NDVI^2 - 0.3215 * NDVI}_{\text{Foliage Water Content}} + \underbrace{\text{stem factor} * \frac{NDVI_{\max} - NDVI_{\min}}{1 - NDVI_{\min}}}_{\text{Stem Water Content}} \quad (1)$$

Based on the vegetation types appearing in our case study, we distinguished between grassland and trees (mixed forest) using the stem factors 1.50 and 12.77, respectively. PET [mm/h] was calculated using an approach based on Lang et al. (2017) and McMahon et al. (2013) and on a proposed simplified version to determine PET from Priestley and Taylor (1972) using Eqn. 2:

$$PET = \alpha \cdot \frac{\Delta}{\Delta + \gamma} \cdot \frac{Q - G}{\lambda} \quad (2)$$

where  $\Delta$  represents the slope of the saturation vapour pressure function [kPa/°C],  $\gamma$  represents the psychrometric constant [kPa/°C],  $Q$  is the net all-wave radiation [W/m<sup>2</sup>],  $G$  is the substrate heat flux [W/m<sup>2</sup>] and  $\lambda$  represents the latent heat of vaporisation [MJ/kg]. Based on Priestley and Taylor (1972) and Lang et al. (2017),  $\alpha$  represents the unity for saturated surfaces and was estimated using Eqn. 3:

$$\alpha = \frac{LE}{\frac{\Delta}{\Delta + \gamma} * AE} \quad (3)$$

AE indicates the available energy [W/m<sup>2</sup>], thus,  $Q-G$ .

### 3 FIRST RESULTS

#### 3.1 Impacts of the 2019 European drought on the evaporative cooling effect

First results show that water-limiting conditions during the summer 2019 impaired evaporative capacities of ecological systems in the city. Mean VWC decreased by  $-0.175 \text{ kg/m}^2$  (Fig. 1 a) in 2019 as compared to 2016 across the entire city. Areas of positive change in VWC (green coloured) highlight sufficient water availability for well-irrigated agricultural land. The deficit in water availability across the entire city is shown to lead to a decrease in the evaporative-driven cooling effect, which is also reflected in a reduced PET (Fig. 1 d). Due to changing surface properties towards drier conditions, less energy is channelled into latent heat, which causes the observable reduction in PET on vegetated surfaces. The evaporative-driven cooling effect across the city appears predominantly soil moisture/water limited, as most of the natural areas shifted to a transitional soil moisture regime due to the lack of water availability. Combined with the observed reduction in VWC (Fig. 1 a, b and c), it is evident that the evaporative capacity of vegetation across the city has been affected by the water-limiting conditions due to the drought.

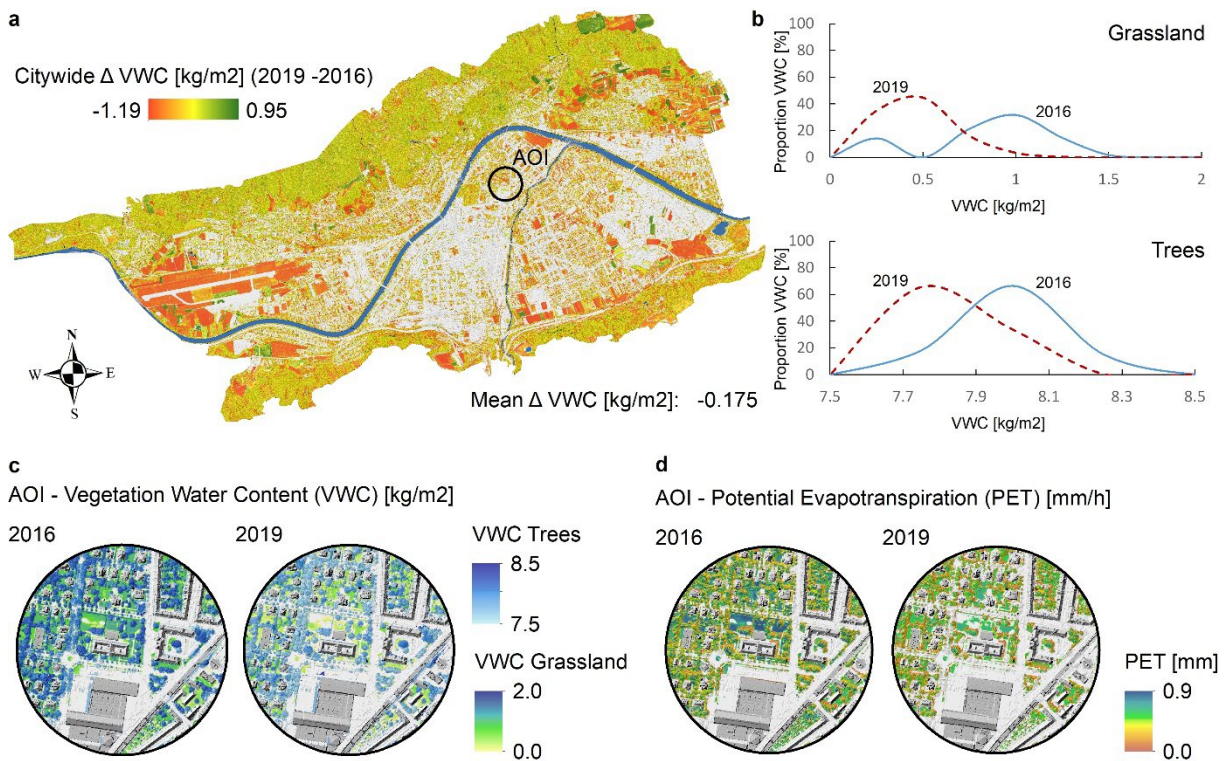


Figure 1. (a) Difference in vegetation water content (VWC) 2019 compared to 2016 in Innsbruck; (b) Proportion of VWC for grassland and trees in 2016 and 2019, the horizontal axes depict VWC, and the vertical axes depict the proportion of VWC values in areas defined as grassland and in areas defined as trees respectively across the entire city; (c) Absolute values of VWC for 2016 and for 2019; (d) Potential evapotranspiration (PET) for 2016 and for 2019.

### 4 CONCLUSIONS AND OUTLOOK

First results analysing water-limiting conditions on vegetation health and evaporative cooling potential highlight the need for sufficient water supply to maintain the evapotranspiration-driven cooling effect during climate extremes. Increasing our cities resilience will require strategic urban water management including both nature-based and technical solutions. Implementation of a comprehensive and sustainable urban water management scheme can connect periods of water deficit and surplus, thus, avoid degradation of ecological and human systems, decrease health risks as well as heat and flood related mortality and infrastructural damage. Ongoing studies will further investigate the effects of water-limiting conditions on land-atmosphere interactions as well as micro- and bioclimatic conditions in the city of Innsbruck. This will provide new insights into heat transfer between the soil, surface and atmosphere during droughts and heatwaves in intraurban areas. Further investigations on possible adaptation measures will help to avoid critical malfunctions in ecological systems interrelating with human well-being under future climate trajectories.

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