Thermal response of a stream to urban conditions – ecological threat or ecosystem service?

Réponse thermique d'un cours d'eau aux conditions urbaines - menace écologique ou service écosystémique?

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RÉSUMÉ

La température détermine les processus chimiques et physiques dans les plans d'eau et limite la présence d'organismes sténothermiques. Les cours d'eau qui traversent les secteurs urbains subissent très souvent de fortes altérations dans leur aspect et leur état. Cette étude évalue l'impact de l'urbanisation sur le régime de température et le bilan thermique d'un ruisseau. Le Lockwitzbach à Dresde (Allemagne) a été équipé de quatre capteurs de température et de deux jauges de débit sur deux sections du ruisseau, toutes les données sont enregistrées avec une résolution de cinq minutes. La partie amont est située à l'extérieur de la ville et présente des caractéristiques rurales, la partie aval est située dans la ville de Dresde et représente une section de cours d'eau urbain. L'étude analyse une année d'enregistrements et conclut que les sections urbains et naturels présentent des dynamiques de température très différentes, surtout en été. Les températures maximales quotidiennes sont jusqu'à 8,3° C plus élevées dans la section de cours d'eau urbain et l'amplitude (moyenne) quotidienne des températures est 0,9° C ou 21% plus élevée que dans la section rurale. Le bilan thermique du cours d'eau dans la zone urbaine montre, un effet d'atténuation sur le climat urbain. Surtout pendant les mois d'été avec une moyenne de 35 MW pendant les tempêtes (mai-sept.'17). Contrairement, le flux de chaleur sensible du cours d'eau apporte en moyenne 1,6 MW à son environnement en hiver (jan.-fév. '18). L'écosystème des cours d'eau urbains est menacé par les impacts hydrauliques et thermiques. D'autre part, les eaux courantes dans un environnement urbain atténuent grandement le climat urbain.

ABSTRACT

Temperature determines chemical and physical processes in water bodies as well as it limits the occurrence of stenothermic organisms. Streams, which cross urban areas undergo very often strong alterations in their original appearance and state. This study assesses the impact of urbanization on the temperature regime and heat budget of a creek. The Lockwitzbach in Dresden (Germany), was equipped with four temperature sensors and two discharge gauges at two stream sections, all data are recorded with five minutes resolution. The upstream section is located outside of the city and shows rural characteristics, the downstream section lies within the city of Dresden and represents an urban stream section. The study analyses one year of recordings and concludes that the urban and natural sections show significantly differing temperature dynamics, especially during the summer. Maximum daily temperatures are up to 8.3° C higher in the urban stream section and the mean daily temperature amplitude is 0,9° C or 21% higher than in the rural section($\Delta\overline{T}_{rural}$ = 3,4° C; $\Delta\overline{T}_{urban}$ = 4,3° C). Thermal budget of the stream in the city area shows, a mitigating effect on the urban climate. Especially, during summer months with a mean of 35 MW during storm events (May-Sept. '17). In contrast, the sensitive heat flux from the stream provides in average 1.6 MW to its surroundings in winter (Jan.-Feb. '18). The ecosystem of urban streams is challenged by hydraulic and thermal impacts. On the other hand, running waters in an urban environment greatly mitigate urban climate.

KEYWORDS

Heat budget, Online Measurement, Urbanisation, Water Temperature

1 INTRODUCTION

Temperature is a crucial factor for energy/matter conversion (Hathway and Sharples, 2012), as well as for chemical and physical processes in water. The occurrence of stenothermic organisms depends on the water temperature (Hardewig et al., 2004). Elevated stream temperatures can indirectly harm fish by lowering dissolved oxygen levels and/or increasing contaminant toxicity. This can cause stress, mortality, or shift species assemblages towards more tolerant species. Apart from water temperature, the effects on stream habitat by urban development are well documented (Krause et al., 2004). Moreover, it is known that the temperature of water bodies causes a cooling effect in urban areas (Somers et al., 2013). Nowadays, in times of urbanization, 54% of the world's population lives in urban areas, a proportion that is expected to increase to 66% by 2050 (UN-Population devision, 2013). These human impacts on waterbodies cause alterations of the thermal regime and consequently the stenothermic organisms/the ecosystem.

2 MATERIAL AND METHODS

The Urban Hydrology Research Group of TU Dresden wants to assess the impact of human settlements on the temperature regime and the heat budget of a small stream. To do so, the Lockwitzbach watershed in Dresden was chosen. The water body is a small middle mountain stream, with a length of 24 km. Its catchment area is about 84 km² (with a mean runoff: 4,1 l s^{-1} km^{-2}). The stream shows different characteristics along the course. Upstream of the city of Dresden, the appearance is rural, while in the municipality these characteristics changes significantly. The rural part has a low population density and only 3,8% impervious surface. In the municipality, the streambed becomes straightened and the imperviousness increases to 41% (see Figure 1).

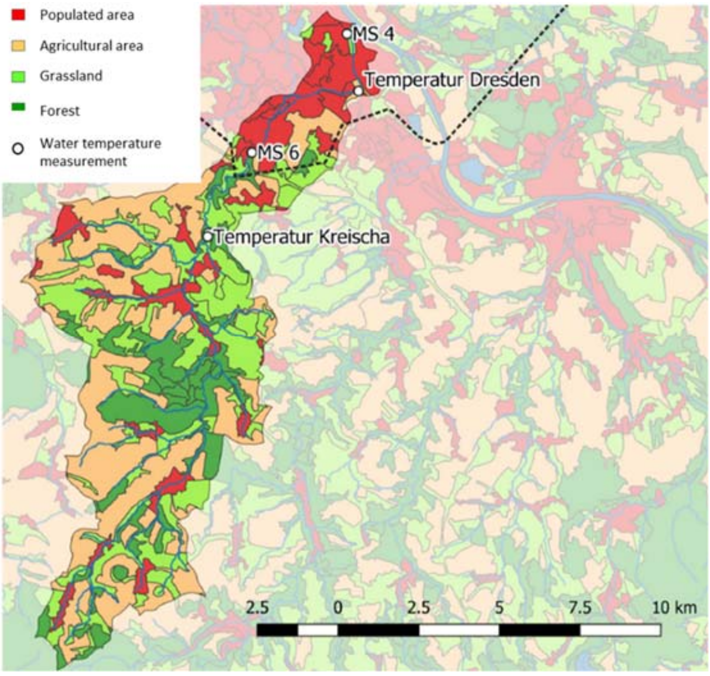

Figure 1: Landuse and measurement locations in the Lockwitzbach catchment (Data taken from the EU Copernicus data base (Langanke, 2017))

The stream is classified as salmonid zone metarhithral creek (Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie et al., 2014). The maximum temperatures concluded in Tab. 1 apply for this type of water body according to the German federal regulation for surface waters (Bundesministeriumder Justiz und für Verbraucherschutz, 2016).

Table 1: Temperature requirements for salmonid zone of a metarhithral creek

Parameter	Very good state	Good state
Maximum summer temperature (April - November) [°C]	< 18	≤ 20
Maximum winter temperature (December - March) [°C]	≤ 10	≤ 10

The Urban Hydrology working group of TU Dresden operates two modular online monitoring stations in the stream (water quality parameters and discharge, for further information see Benisch et al. (2017)). The first at the border between the rural and urban sub catchment (MS 6) and the second one after a flow distance of ca. six kilometers, shortly before the confluence with the river Elbe (MS 4). Additional to these stations, two water level / temperature loggers (**Erreur ! Source du renvoi introuvable.**) were installed in the stream (Temperatur Kreischa & Temperatur Dresden, see Figure 1). This setup allows the comparison of water temperature development within the two sub catchments (rural and urban) in detail. Water temperature and discharge (MS4 & 6) were recorded in a 5 min. interval, flow rates are calculated using stage-discharge-relations for continuously logged water levels. Analysis of the recorded time series has been done with R Studio (R Development Core Team, 2008) using the xts (Ryan and Ulrich, 2018) and hydroTSM package (Zambrano-Bigiarini, 2017).

3 RESULTS

To display the impact of an urban areas by changes on water temperature one year of water temperature recordings (April 2017 –April 2018) are shown in Figure 2 and will be further evaluated.

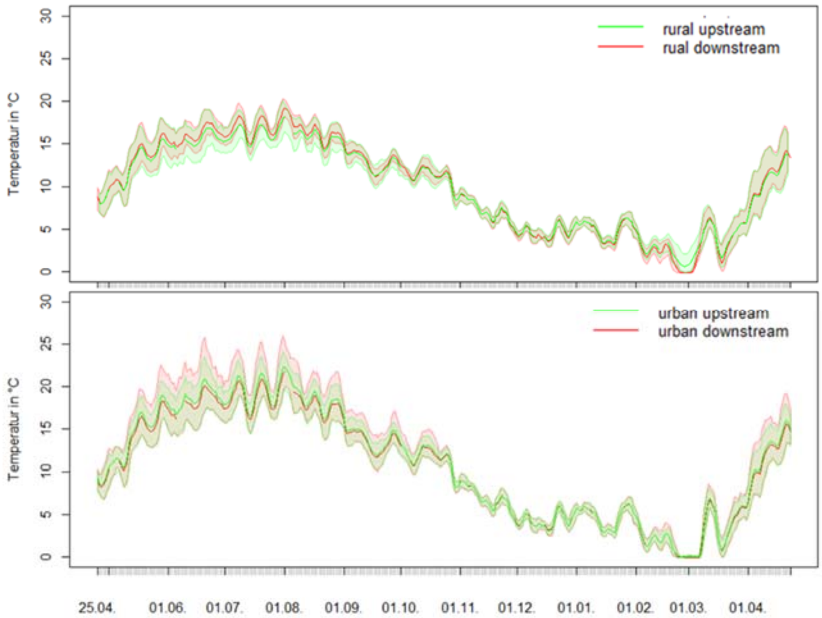

Figure 2: Mean daily water temperature together with maxima and minima (transparent polygon) of the rural (upper graph: Temperatur Kreischa & MS 6) and urban catchment (lower graph: Temperatur Dresden and MS 4; lines smoothed)

Based on the temperature measurements from the sensors it becomes obvious that the mean water temperature in the urban catchment increases heavily during the summer months (June, July, August), especially in the urban part (sensor recordings in flow direction; Temperatur Kreischa; MS6; Temperatur Dresden, MS4: 15,86°C /16,50°C /18,36°C /18,9°C). Similarly, but with lower magnitudes, these increase are present in autumn (September, October, November) and spring (March, April, May) with: 8,81°C /8,89°C /9,43°C /9,72°C and 10,46°C /10,54°C /10,73°C /10,89°C, respectively. In contrast to that, the mean water temperature shows the opposite trend and drops during winter months along the flow path (4,12°C /3,92°C /3,66°C /3,65°C). Furthermore, not only the mean temperatures show a significant difference between the rural and the urban catchments, the diurnal patterns of heating and cooling also differ. To quantify this with numbers, daily maximum and minimum temperatures were calculated for each sensor and differences between the sensors in the rural and urban catchments were calculated (ΔT_{max} / ΔT_{min}, results are displayed in Table 2). Looking at the summer months again, the daily maximum temperature does not vary much between the sensors in the rural catchment, whereas in the urban area a steep increase is distinguishable (see Figure 2). The opposite happens during night, where the stream cools down in the upper part and does not change much within the city. Spring and autumn already show a similar behavior, however on a smaller scale. Differences in maxima/minima temperatures in the winter are almost negligible in the urban catchment, in the other catchment a mutual decrease of both, ΔT_{max} and ΔT_{min}, can be seen.

Table 2: Comparison of measurements in the rural part (Temperatur Kreischa to MS6) and the urban part (Temperatur Dresden to MS4), mean differences of the daily maxima- and minima temperatures (ΔT_{max}, ;ΔT_{min} = $T_{downstream} - T_{upstream}$)

	Winter (Dec., Jan. Feb.)	Spring (Mar., Apr., May.)	Summer (Jun., Jul., Aug.)	Autumn (Sep., Oct., Nov.)
Rural				
ΔT_{max}	-0.306	-0.143	0.201	-0.127
ΔT_{min}	-0.211	0.177	1.164	0.277
Urban				
ΔT_{max}	0.038	0.610	1.327	0.412
ΔT_{min}	-0.039	0.086	0.104	-0.054

The energy transfer between the measurement stations MS6 (outlet of rural stream section) and MS4 (outlet of urban stream section) were calculated for each station by:

$$\boldsymbol{E}\ [kW] = \rho \left[\frac{kg}{m^3}\right] * Cp \left[\frac{kJ}{kg*K}\right] * \Delta Q_{MS4-MS6} \left[\frac{m^3}{s}\right] * \Delta T_{MS4-MS6}\ [K]$$

We assumed (a) the specific heat and density are constant trough the temperature change (b) ρ_{water} = 1000 kg m^{-3}, and (c) $c_{p,water}$ = 4.186 kJ $kg^{-1}K^{-1}$. For ΔQ and ΔT the differences between the measurement stations were used. The presented results in Figure 3 show, that during dry weather conditions the heat transfer is not of great importance, except for the winter months (01.01.18-14.03.18), where an average warming (energy input to the surrounding area, indicated by a negative heat flux) of -1.6 MW to the urban area can be seen. However, during summer rain events, heat export from the urban area increases considerably with a mean energy flux of 35 MW (selection threshold: Events higher 10 MW) and peaks up to 209 MW.

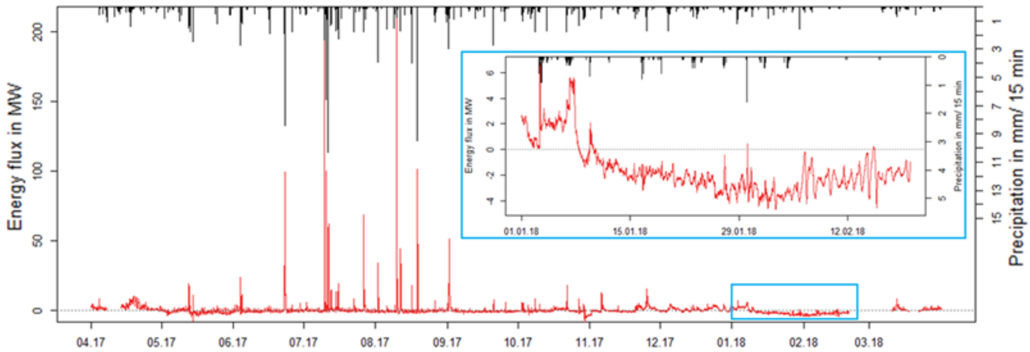

Figure 3: Hourly energy flux rates between MS6 and MS4, with a focus on the beginning of 2018 (in the blue box). Gaps result from deleted wrong water level recording; the stream surface was frozen

4 DISCUSSION

The presented values show clear, how the thermal regime of a stream is changed by anthropogenic influences on its catchment properties. The main drivers of these effects are suggested to be the changes in the urban riparian zone, where trees are lacking for providing shading as well as insulation. This zone is barely/not present in the urban sub catchment, furthermore the riverbed got straightened and rearranged with a wide trapezoidal cross-section. A small water level and a broad water surface results from this constructive measure, offering greater potential for heating by solar radiation. The extreme dry and hot year 2018 has not been evaluated for this extended abstract, however first insights exceed the recordings from 2017 with water temperatures higher than 30° C and an increase in water temperature by 9.5° C along the 6 km flow distance between MS6 and MS 4. The temperature is also a valuable indicator for biological processes and their effects on water quality parameters in the urban catchment. We measured, for example, extremely oxygen oversaturated water and very alkaline pH values, both with huge ranges in their diurnal amplitude. The heat flux analysis shows, that running waters greatly mitigate urban climate during rain events in the summer. To identify the main drivers of this heating processes we will start to work with an inverse distance weighted evaluation of the catchment characteristics (sealed surface/land use, elevation). A still unknown and difficult to answer question is the effect of groundwater infiltration/exfiltration along the stream course and its effect on the water temperature.

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