Report by UWI doctoral researcher Anne Timm (T1)

Project number: T1

First and last name of doctoral researcher: **Anne Timm**

(Working) title of doctoral project: **Water and heat transport of paved surfaces**

Name of supervisors: Prof. Dr. Gerd Wessolek (TUB), Prof. Dr. Martin Jekel (TUB), PD Dr. Bettina Detmann (Albers) (Uni Essen), Dr. Thomas Nehls (TUB)

2. Description of doctoral project and research results achieved to date:

Motivation

Urbanisation has been recognized as a driving force of change of environmental processes in many disciplines. One characteristic commonly associated with growing urbanisation is the sealing of natural surfaces with different paving materials. The hydrological balance of paved surfaces, as the urban soil-atmosphere interface, differs from natural ones [1]. The urban hydrological balance has been studied and modelled for decades [2,3]. Due to safety concerns, storm water management and flooding have been the focus [4]. However, very few actual measurements have been published [5,6,7], leading to a lack of knowledge on the underlying processes and the resulting hydrological balance of paved surfaces. This makes accurate modelling and evaluation of different urban settings difficult. Hence, more research was needed to better understand and manage the hydrological balance of paved surfaces.

Methods

Two weighable lysimeter (Fig. 1) were used to measure the hydrological balance of two common paving surfaces, cobblestones and concrete slabs, at a high temporal resolution (resulting in hourly data). High temporal resolution relied on making use of weighable tipping buckets [8], which allowed the recording and assignment of even small runoff amounts which would not have resulted in a tipping event. Additionally, sensors were installed at the surface and within the underlying soil layers in order to measure heat and water transport processes (temperature and soil moisture content). This combination of methods and an increased temporal resolution allowed detailed observations of processes. The lysimeter are part of a joint lysimeter station in Berlin-Marienfelde, operated by the Technische Universität Berlin and the Umweltbundesamt (UBA). As part of this larger lysimeter station, a climate station situated very close to the two paved lysimeters provided hourly climatological data. After a reconstruction period, data was collected over a measurement period of one year. An additional experiment was conducted to observe surface wetting-drying processes. A thermal camera was used to obtain thermal images and surface temperatures after wetting the surfaces and the following evaporation processes. Utilising the measured data, relationships between hydrological processes, heat transport and climate data was researched. In a final step, the TUBGR model, an previously existing annual model for estimating evaporation from paved surfaces [9] was tested, followed by a discussion of potential approaches to increase the temporal resolution of the model.

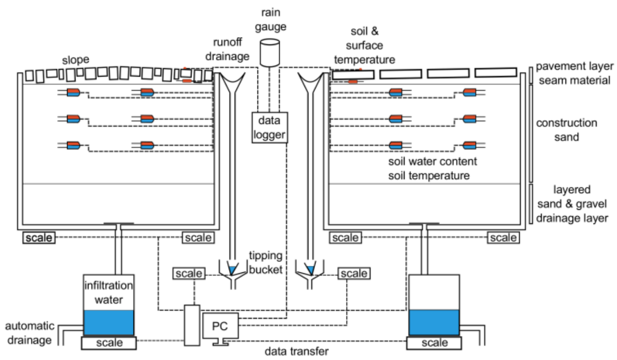

Figure: 1: Lysimeter setup

Results

Since few previous studies provided annual hydrological balances, the overall and seasonal balances confirmed and expanded previously existing research (Fig. 2). Annually, cobblestones evaporated 25 % and rarely produced runoff (3 %). Concrete slabs tended to produce more runoff (16 %) and less evaporation (22 %). Both surfaces led to similar infiltration (62 %), with most infiltration taking place during winter. In case of cobblestones, evaporation was twice as high in summer. Runoff generation depends on the rainfall intensity and duration. For cobblestones, 44 % of all runoff was generated on just two days with high intensity precipitation events.

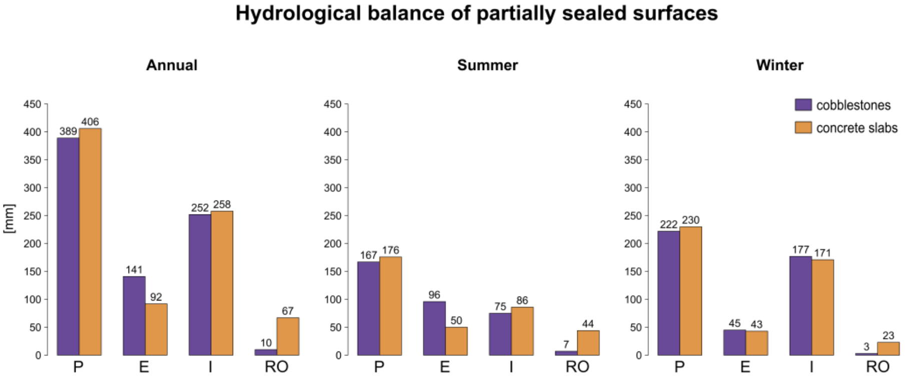

Figure 2: Annual and seasonal hydrological balances

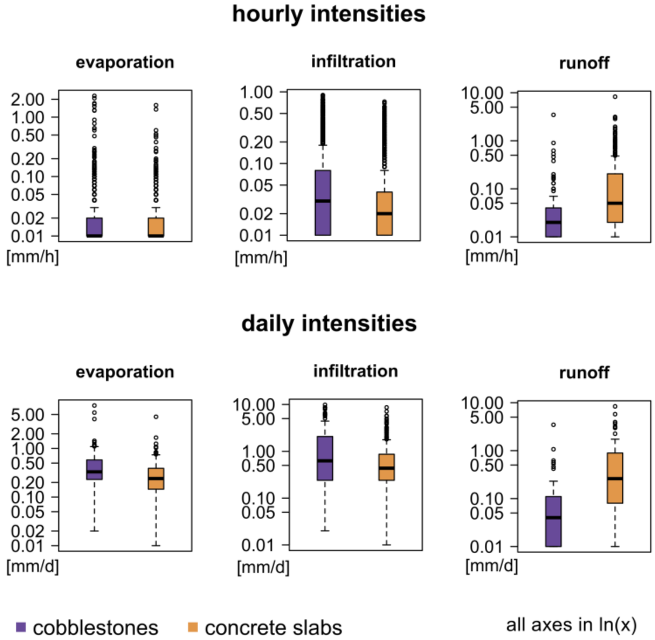

Figure 3:1 Hourly and daily intensities (for values > 0)

On an hourly basis (Fig. 3), evaporation events (where E > 0) tend to have a very low rate with a median value of 0.01 mm h^{-1}. The highest hourly evaporation rates are 2.28 and 1.59 mm h^{-1} for cobblestones and concrete slabs, respectively. On a daily basis, the median rate for evaporation events are 0.33 mm d^{-1} (cobblestones) and 0.24 mm d^{-1} (concrete slabs). Again, cobblestones reach a higher maximus of 7.64 compared to 4.48 mm d^{-1}. While cobblestones tend to higher infiltration rates, nearly 50 % of the days registered no infiltration for this surface. Contrary to that, concrete slabs had more consistent infiltration with only 9 % of all days without infiltration. Runoff occurred very rarely for both surfaces, with 76 − 80 % of all days without runoff. If runoff takes place, concrete slabs exhibit significantly higher rates with a median of 0.05 mm h^{-1} or 0.26 mm d^{-1} compared to 0.02 mm h^{-1} or 0.04 mm d^{-1} for cobblestones. The maximum values were 3.46 mm h^{-1} or 3.46 mm d^{-1} (cobblestones) and 8.25 mm h^{-1} or 8.37 mm d^{-1} (concrete slabs). In both cases, the highest daily runoff rate can be attributed to a high-intensity rainfall event taking place within a single hour.

The combination of lysimeter data revealing water transport processes leaving the system and sensor data recording the water movement within the system offered new insights into processes and their interactions. Upward water transport from underlying soil layers led to evaporation processes during dry periods in which no precipitation resulted in water input. This effect contributed 47 % of evaporation for cobblestones and 13 % for concrete slabs. The combined results also show that for paved surfaces, water and heat transport are closely coupled.

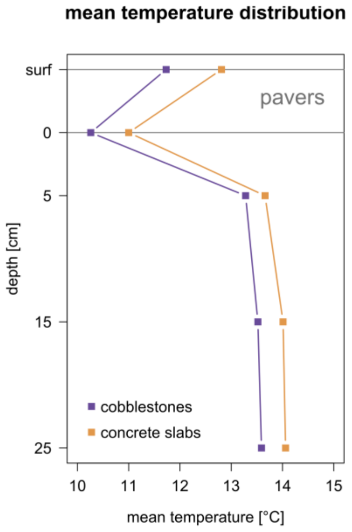

Figure 4: Mean surface and soil temperature profile

Both surfaces led to higher soil temperatures compared to natural surface covers, with concrete slabs tending to slightly higher temperatures (Fig. 4). In general, the upper layers, especially surface and paver, are most exposed and hence influenced by atmospheric conditions. Temperature fluctuations are highest at the surface and decrease with depth.

Efforts were made to estimate evaporation of paved surfaces based on climate data. This may be accomplished by reducing the common grass-reference evapotranspiration. For annual estimations, the pre-existing TUBGR model which calculates an annual and constant reduction factor yielded good results. Based on the lysimeter measurements, empirical seasonal and monthly reduction factors could be derived. Additionally, an approach for estimating this monthly factor from monthly air temperature is introduced. However, this concept would require additional data sets, ideally set in different climatic zones.

Overall, the study shows that pavements are more than a runoff generator. The urban soil-atmosphere interface is an active system with varying impacts on the urban hydrological balance. Understanding and utilising these differences has the potential to improve the design of urban areas.

Current State of Work

Research work has been completed, resulting in one publication and a doctoral thesis which contains the previously published part and additional content. The thesis was submitted on 29.06.2018 and the doctoral procedure initiated. Defence of the thesis expected in fall 2018.

Collaboration

A shared measurement site, the lysimeter station Berlin-Marienfelde, as well as thematic closeness resulted in a high degree of collaboration with project N2 (Kyle Pipkins). Both projects provided essential data for the other one. Thematic closeness lead to an active exchange of information and literature. A close collaboration was also achieved with Dr. Basem Aljoumani, who provided insight and support, and further analysed the data produced within this project. The research project is part of the common topic groups "Urban soil-atmosphere interface and "Modelling".

References

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3. Comments on the qualification programme and supervision strategy:

The overall qualification programme was well organised, interdisciplinary, interesting and useful. The core courses offered insights into research areas that have not been part of my education so far, and were essential to communicate and collaborate with the other doctoral candidates. I was able to attend numerous additional training courses, both research related (e.g. programming, advanced training in the field, etc.) and collaboration-focused (e.g. science communication). Additionally, the courses organised specifically for female doctoral students (e.g. time management and leadership) proved extremely relevant for personal development and my outlook on the time after the doctoral degree. I enjoyed the regular interim meetings and summer schools, which offered perfect opportunities to connect with other students and everyone else involved in UWI.

As one of the elected doctoral student speakers, I became part of the internal steering committee (ISC). This was a great opportunity to gain insights into the organisation and management of the project. Additionally, I took part in the strategy meetings, in which external advisors assessed the programme. These experiences will be very useful in the planned path after finishing my PhD. During my work in the ISC, I felt that all other members were always interested in the view and opinion by the students. The feedback and suggestions provided by doctoral students were incorporated into the program.

Participation in the following Research Training Group events:

1. Core courses
   - I – Urban interface processes – fluxes, transport, interactions (3 ECTS)
   - II – Modelling and measuring concepts of interface processes (3 ECTS)
   - III – Urban freshwater ecology (3 ECTS)
2. Elective courses
   - Summer School on Flow and Transport in Terrestrial Systems (1.5 ECTS)
   - CCES Winter School "Science Meets Practice" (4 ECTS)
   - HYDRUS Workshop (equivalent to 2 ECTS)
   - Introduction to Python (equivalent to 5 ECTS)
   - Time management, conflict management and networking training at TU Berlin
3. Gender courses
   - Time is honey – the new approach to time, self and workload organization
   - Self-positioning
   - Negotiation
   - Project management
4. UWI lectures: Participated in all UWI lectures if possible
5. Other UWI events
   - Orientation Seminar and UWI Opening Ceremony (08. – 09.09.2015)
   - Exposé Talks (08.12.2015)
   - Summer School 2016 (13. – 14.09.2016)
   - Collegiate Seminar (22.09.2016)
   - Student Research Council (17. – 18.03.2017)
   - Interim Meeting (19.05.2017)
   - Summer School 2017 (05. – 06.09.2017)
   - Summer School 2018 (19. – 20.09.2018)

Research stays or internships at other research institutions both at home and abroad:

- None

Participation in conferences, congresses, etc., at home and abroad:

2015:

- Summer School on Flow and Transport in Terrestrial Systems (27. – 31.07.2015, Halle, Germany)
- International workshop: Lysimeter – separating processes in flux measurement (21. – 23.10.2015, Freising, Germany)

2016:

- CCES Winter School "Science Meets practice (11. – 14.01.2016 and 01. – 04.02.2016, Wislikofen, Switzerland)
- HYDRUS Short Course (22. – 24.03.2016, Prague, Czech Republic)

2017:

- Wasser Berlin International, Berlin (28. – 31.03.2017)
- EGU 2017 (23. – 28.04.2017, Vienna, Austria)
- International Conference on Urban Drainage 14 (22. – 27.05.2017, Prague, Czech Republic)
- SUITMA Soils of Urban, Industrial, Traffic, Mining and Military Areas 9 (10. – 15.09.2017, Moscow, Russia)

2018:

- EGU 2018 (08. – 13.04.2018, Vienna, Austria)

4. Individual publications:

I. Articles:

- Timm,A., Kluge,B. & Wessolek,G. (2018): Hydrological balance of paved surfaces in moist mid-latitude climate – A review. Landscape and Urban Planning, 175, 80-91

II. Conference, poster presentations etc.:

- Pipkins,K., Kleinschmit,B., Wessolek,G. & Timm,A. (2017): A spatial-temporal method for assessing the energy balance dynamics of partially sealed surfaces. 37th *International Symposium on Remote Sensing of Environment* (8. –12.5.2017, Tshwane, South Africa), poster presentation.
- Timm,A. & Wessolek,G. (2017a): Hydrological balance and water transport processes of partially sealed soils. *EGU General Assembly 2017* (8.-13.4.2017, Vienna, Austria), abstract and oral presentation.
- Timm,A. & Wessolek,G. (2017b): Studying the hydrological balance of (partially) sealed surface using high precision weighable lysimeter. *17. Gumpensteiner Lysimetertagung* (9.-10.5.2017, Raumburg-Gumpenstein, Austria), conference paper.
- Timm,A. & Wessolek,G. (2017c): Hydrological balance and water transport processes of partially sealed soils. *Soils of Urban, Industrial, Traffic, Mining and Military Areas - SUITMA 9* (22.-27.5.2017, Moscow, Russia), abstract and poster presentation.
- Timm,A. & Wessolek,G. (2017d): Hydrological balance and water transport processes of partially sealed surfaces. *14th IWA/IAHR International Conference on Urban Drainage* (10.-15.9.2017, Prague, Czech Republic), extended abstract and oral presentation.
- Timm,A. & Wessolek,G. (2018): A high-resolution lysimeter study of water transport processes of paved surfaces. *EGU General Assembly 2018 (8.-13.4.2018, Vienna, Austria), abstract and PICO presentation*