Report by UWI doctoral researcher Nasrin Haacke (W2)

Project number: W2

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(Working) title of doctoral project: **Scaling and connectivity assessment of critical source areas of diffuse pollution in urban catchments**

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

State of the art

Urban areas contain numerous diffuse sources of contaminants, which are released during rainfall and discharged into urban drainage systems. Important sources of such contaminants include surfaces of buildings, structures, streets, highways, and green areas, which are exposed to wash-off processes driven by rainfall and runoff (Wicke et al. 2015). Wash-off processes often facilitate the release of pollution into urban stormwater by the physical detachment of materials accumulated on surfaces as well as dissolution of materials and chemicals (including emerging contaminants) and finally transport in the form of runoff into the sewage systems or nearby surface water bodies. Diffuse pollution is often from a range of sources that may have no effect on the water environment individually, but at the scale of a catchment, it has a significant effect on water quality. It includes toxic chemical pollutants (Pal et al. 2014), heavy metals (Barałkiewicz et al. 2014, Poudyal et al. 2016, Soltani et al. 2014), organic contaminants like pharmaceuticals but also life-cycle compounds (Bürgel et al. 2016, Jurado et al. 2012, Roder Green et al. 2014) and fecal matter. In this respect, urban runoff is difficult to control, due to the intermittent nature of rainfall events and the variety of sources. The distribution and magnitude of contaminant releases varies depending on the source characteristics, urban surface types, the intensity, duration and timing of the rainfall event generating wash-off processes (Göbel et al. 2007).
One task of urban hydrology is keeping the degree of sealed areas as small as possible to minimize runoff. However, that is particularly difficult in densely built inner city areas. An important partial-sealed buffer are areas such as cobblestone pavement, where infiltration in the upper soil is encouraged.
To quantify this effect, detailed analyses of different pavement materials were carried out during the first cohort of UWI by Timm et al. (2018) examining water transport processes and the resulting hydrological balance under a changing regime of rainfall intensities. More precisely, data of retention capacity, evaporation and infiltration were collected to classify the materials in different sealing degrees. Investigated pavements include asphalt, concrete plates, sett stones, brick and cobblestone and also grass pavers and pervious asphalt. Timm et al. (2018) came to the conclusion, that for nearly all paving materials where infiltration and evaporation takes place, the runoff volume has been reduced significantly.

However, the development of diffuse pollution management strategies requires a detailed understanding of the vertical spreading of diffuse pollution through different surface types as well as their mobilization and transport in horizontal orientation by heavy rainfall events in a catchment. Especially the scaling of first-flush concentrations from individual surfaces to urban catchments scales were not analyzed in regard to the resulting pollution concentrations in sewer systems and urban rivers.

Motivation and research idea

In urban areas, a large amount of anthropogenic diffuse substances is redistributed from urban catchments into the surface waters and the groundwater as a function of temporal and spatial variability of rainstorms (Bürgel et al. 2016). Pollutant concentrations can be substantially higher during the initial period of the runoff, hydrograph commonly known as first-flush (Poudyal et al. 2016). Analyses of first-flush concentrations (suspended solid and chemical oxygen demand) in an urban catchment demonstrated, that more than 50% of both loads were transported by the first 30% runoff volume (Li et al. 2012). Furthermore, pollution from urban stormwater discharge was identified as one of the major causes of surface water quality deterioration (Novotny 1999).

Referring to the study area, Berlin provides its drinking water within its own urban area, where inflowing groundwater and bank filtration represent the major constituents (Möller & Burgschweiger 2008). Here, it is of great interest to mitigate and restrain the spread of pollutants. To assess the spread of pollution it is important to analyze when exactly high-intensity storms occur in the study area causing flash floods. On this basis, further steps can investigate a potential connectivity between high-intensity storms, diffuse pollution and drainage systems.

Scientific project relevance

The identification of critical source areas under intense or extreme weather conditions contributes strongly to both, water supply and water resources management. Here, the assessment of the applicability and development of connectivity indices will help to classify areas in cities and stress areas where acute action is required. The spatial and temporal analyses of high-intensity storms on different scales will identify time periods and locations where an overloading of drainage systems could lead to direct discharge into surface water bodies and/or result in overloading and connected flooding of sewage systems. Thereby, pollutants of different nature can be carried along unfiltered and thus pose a risk for human and environmental health. To identify these critical pollutants and investigate the connectivity between diffuse pollution and the drainage systems during different high-intensity storms across the seasons is therefore of strong interest.

Research demands

To further clarify the scope of the project, the following scientific questions are designed to be answered during this project:

1) How do high-intensity storms causing significant amount of urban runoff develop over time and space in urban areas across Germany and do trends in probability recurrence of certain rainfall events exist?
2) How do different influence factors such as intensity and duration of rainfall and urban surface types affect the mobilization of pollutants in urban areas?
3) Which pathogens and pollutants are prevalent in urban runoffs when it comes to a flooding of sewage systems and how are they re-distributed in street canyons during an urban flash flood event?

Objectives

The main objective of this project is an advanced hierarchy and connectivity assessment of critical contaminant source areas in urban catchments under a changing regime of high-intensity storms. This research will focus on the spreading of different diffuse pollutions in urban catchments considering variabilities in duration and intensity of precipitation, contaminant concentrations and urban surface types. For these different indicators, connectivity has to be investigated and evaluated, including so-called connectivity indices, to identify critical source areas. Furthermore, the degree of connectedness to urban drainage systems will be evaluated to derive a holistic approach for a new, sustainable water resources management for cities.

Work programme incl. proposed research methods

Before going into detail on my own research topic, basic knowledge is acquired. This will be realized by attending the offered core courses and elective courses (chap. 3). Furthermore, an understanding of the holistic UWI concept is necessary in order to identify smaller and larger interfaces between my own and other projects. Knowing these interfaces is of major importance for further collaboration.

To become more familiar with the state of the art of my research topic, and extensive and profound literature research has been done and will continue constantly as an ongoing process. To manage bibliographic data and related materials, Zotero is used, a free and open-source reference management software. This software has been chosen because it is straightforward and reliable. Furthermore, it does a good job of importing bibliographic information from the Web and adding notes, tags and attachments to your items is another strength of this software. In a further step, categories were defined after certain key words and papers were newly organized to get a better overview.

Presenting the research topic to the department and writing this exposé is also included in this procedure as well as meeting with the Board of Supervisors. Further internal workshops are planned to narrow down and specify the research topic.

The next step of the project process is going to be focused on high-intensity storms across Germany. Here, the goal is to gather and analyze precipitation data, to interpret them and finally put them in a larger scale spatial and temporal context.

<u>WP1: High-intensity storms in Berlin and across Germany</u>

Analyzing the effect of a high-intensity storm on pollutant transport in urban catchments requires an overall understanding of these events in our geographical location including knowledge about e.g. their occurrence and the return probability. Therefore, long-term data sets (>25 years) are necessary to carry out time series analysis as well as spatial data analysis and statistics.

For data analysis and being able to make predictions, it is essential to be familiar with the techniques of Geostatistics. Here, R is a helpful programming language and free software environment for statistical computing and graphics. It has been chosen due to its popularity in science and its wide variety of statistical and graphical techniques, including linear and nonlinear modeling, classical statistical tests, time-series analysis, classification, and others.

For Germany, rain measurements with a high temporal resolution over long time periods can be obtained from the German Weather Service (DWD) for existing weather stations (Climate Data Center DWD 2018). More precisely, the DWD provides precipitation depths in a range of aggregation times, e.g. 1 minute, 10 minutes, hourly, daily, monthly and annually. Besides, the data are classified in historical and recent, whereby the historical data reflect the precipitation data from the beginning of the recording (differs from station to station) until the end of 2017.

One of the first tasks is to characterize the city of Berlin with respect to its precipitation extremes by presenting precipitation statistics. The main objectives are to find out when high-intensity storms are likely to occur (during the day, the season) and to get an overview when extreme events occurred over the last 25 years. In a pilot study, eight stations were used across the Berlin city area. Due to the large amount of existing data, the focus of interest is limited on precipitation duration with one hour and two hours in time resolution.

To analyze return intervals for events with different aggregation time, a special catalogue requiring return intervals of heavy rainfall events, called KOSTRA (Koordinierte Starkniederschlagsregionalisierung und -auswertung: Coordinated heavy precipitation regionalization and evaluation, (Malitz & Ertel 2015)) has been used. This catalogue was primarily developed by the DWD for the design of water management facilities and includes calculated regionalized precipitation levels emerging from analysis of historical rainfall events and statistical calculations.

To check seasonal tendencies, the non-parametric Mann-Kendall test will be used (Fiener et al. 2013). It is a rank-correlation approach widely used in hydro-meteorological studies for determining the extent to which the data show a monotonic trend. The steepness of the slope in monotonic increase or decrease in the data of a time series is given as Mann–Kendall's τ (1 = monotone increasing trend; 0 = no trend; −1 = monotone decreasing trend).
In a further step, the time-series analysis will be extended including 15-20 locations across Germany to get a spatial overview of intense rainfall events.

WP2: Connectivity assessment using lab- and field-experiments
This working package concentrates on the connectivity of different surface types and areas and the sewage system in urban catchments as well as on lab-experiments (Fig.1) investigating and assessing previously established connectivity theories. These experiments will be carried out, both, on lab and field scale and will be an analog to the field experiment in WP3.
As already mentioned, connectivity assessment to identify critical source areas or water bodies at risk from human activities has not been used in urban areas so far. Nevertheless, it is becoming more important and significant especially in terms of stricter requirements in water quality of surface water bodies.
Landscape connectivity was discussed intensively in a group of researchers, engineers and scholars using COST (European CO-operation in Science and Technology), the longest-running European intergovernmental network for cooperation in research and technology. One goal within this organization is to extend the understanding of connectivity in landscapes to urban areas to tackle similar problems. Here, an active participation in conceptual development is planned by assessing connectivity using lab-experiments for different case studies.

For lab-experiments it is necessary to know which dependencies of parameters should be investigated. Here, of special interest are investigations of different intensities and durations of high-intensity storms on the pollution transport. More precisely, two investigations can be carried out:

1) Pollution transport on different surface types connected to one high-intensity storm event
2) Pollution transport on one surface type under a changing regime of high-intensity storms.

Based on this, first-flush experiments and/or rainfall experiments will be used to analyze temporal changes of first-flush concentrations, including variations in rainstorm intensity and urban surface types.

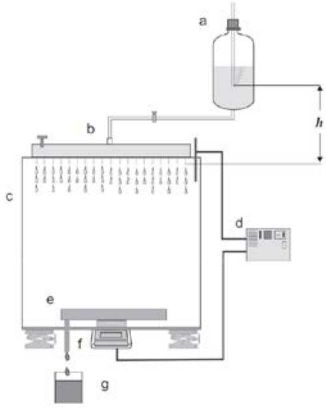

Fig.1: Experimental setup for the rainfall simulation after Roder Green et al. (2014): (a) Mariott's bottle, (b) needle irrigator, (c) hermetically sealed plexiglas box, (d) data logger, (e) stainless steel tray, (f) digital scale, (g) runoff collection, and (h) pressure difference, adjusted

WP3: Real-time analysis of urban flash floods (task force)

A task force is an organizational form of data collection which focuses on the investigation and analysis of recent or immediate damaging events or natural disasters. Directly after the occurrence of a major natural disaster (such us urban flash flood, but also used for the investigation of other natural hazards such as destructive earthquake or tropical cyclone), a rapid collection and processing of data is carried out under real-time conditions by a larger group of scientists and graduate students. As the sampling date cannot be fixed in advance and may occur at any day (or night) during a period of weeks or months, the action needs careful planning, preparation of all required equipment and instruction of a larger group of participants as well as a continuous update of a schedule of availability of the participants.

A task force action is planned to sample the irregularly occurring flash floods in the city area of Berlin to assess water pollution and the correlated health hazard from flooded streets and pavements. For this purpose, it is necessary to plan in advance which locations in Berlin are particularly suitable for sampling. Here, the results of the statistical analysis of WP1 can be used to decide which catchments are especially suitable for taking samples from runoff, released sewage water from the canalization and puddles. In this context, samples can be taken during the flood and directly after the flood to investigate variations in concentration during time. To sample the first-flush should also be attempted but is more difficult to organize and implement. A special focus will also be on pollutants that are not necessarily known as being present yet. Especially in the case of rising water from sewer systems it should be checked which pathogenic germs are temporarily on the roads and can lead to health hazards for humans.

Collaboration

Strong cooperation of this project is planned with project **H2** for water quality modelling and with Franziska Tügel (Chair of Water Resources Management and Modelling Hydrosystems, Technical University Berlin) for modelling flash floods in small catchments.

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3. Comments on the qualification programme and supervision strategy:

Participation in the following Research Training Group events:

1. Core courses
   - Urban interface processes – fluxes, transport, interactions (3 ECTS)
   - Urban freshwater ecology (3 ECTS)
   - Modelling and measuring concepts of interface processes (3 ECTS)
2. Elective courses
   - Water resources management (6 ECTS),
   - Large-scale hydrological modelling (3 ECTS)
   - Schadstoffabbau (3 ECTS)
3. Further courses
   - Time management, career planning and optimize your scientific advisers and network 2018 (3 ECTS)
   - Talk the talk and walk the walk (3 ECTS)
   - Let's go! We planned and motivated for the doctoral project (3 ECTS)
   - Basics of project management (3 ECTS)

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

To gain a better understanding of the assessment of connectivity and the quantification of pollution transport under a changing regime of high-intensity storms an internship at University of Newcastle, UK, is under discussion.

Conferences:

1) EGU 2020, Vienna, Austria
2) COST ACTION Conference 2019
3) International Conference of Urban Drainage 2019, Vancouver, Canada