# Adaptation and Transfer of the Urban Water Balance Model ABIMO

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## Highlights

- The open source model ABIMO allows for a simple calculation of the urban water balance.
- The deviation from the annual natural water balance can be used to detect hotspots for WSUD.
- Transferability of ABIMO is currently tested between the German cities of Berlin and Cologne.

## Introduction

The increasing frequency of extreme weather events poses significant challenges to densely populated urban areas, through issues such as heat stress and floods. The dense construction in urban areas exacerbates these challenges by promoting runoff formation during heavy rainfalls, hindering infiltration, and reducing evaporation due to the lack of green or blue infrastructure.
This paper explores a novel approach for measuring the potential impact of extreme weather events, using the "deviation from the natural annual water balance", as suggested by the German Water Association in the technical guidelines DWA-M 102-4/BWK-M 3-4 (DWA, 2022).
The deviation considers three key components of the local urban water balance: surface runoff, infiltration into the ground, and evapotranspiration. The three components are simulated with an extended version of the Water Balance Model ABIMO - originally developed for agricultural water balance assessment by the German Federal Institute for Hydrology, and later adapted to the urban environment for the specific case of Berlin. Recently, we have investigated the possibility of transferring the application of the model to other cities, specifically using data provided by the city of Cologne, Germany.
The work presented enhances the accuracy and transferability of ABIMO, while also proposing an indicator to support decision-making processes regarding urban stormwater management.

## Methodology

**The Water-Balance-Model ABIMO**

The open-source Water-Balance-Model ABIMO allows quantification of the three components runoff, evaporation and infiltration of the annual local urban water balance. Its source code is written in the C++ programming language, and a wrapper function has been written to access ABIMO from a R-environment (KWB, 2022; Umweltatlas, 2022).

ABIMO relies on three main categories of input data:
1. **Climatic data**: Precipitation and Potential Evaporation in mm/yr.
2. **Land use data**: Specific characteristics of the area, including urban land use and imperviousness.
3. **Soil, vegetation, and groundwater characteristics**: Parameters like usable field capacity, rooting depth, and distance to the groundwater table.

The original calibration of the model was performed using lysimeter measurements of evapotranspiration and percolation for different types of soil and vegetation (Bonta & Müller, 1999). In its application on the city of Berlin, analogous parameters were defined that govern the same phenomena for different kind of surfaces, such as roofs, roads and other paved surfaces. Unpaved areas are treated separately in the model, estimating the evaporation through the *Bagrov-Equation* that defines the relation between precipitation,

potential evaporation and real evapotranspiration (Glugla, et al., 1999). The so-called “yield class” plays a fundamental role in this estimation, being a measure for the quantity of vegetation on a certain area.
In the context of our study, a thorough investigation of ABIMO’s internal processes has been conducted: To allow testing and further adaptation a translation of the model from C++ into the programming language R was performed.

**Deviation from the Natural Water Balance**

Based on the idea of the German Water Association (DWA, 2022), a parameter ΔW is introduced to quantify the deviation of the water balance from its natural state as:

$$\Delta W = \frac{1}{2}\left(|ev_{nat} - ev_{urb}| + |ri_{nat} - ri_{urb}| + |rs_{nat} - rs_{urb}|\right)\frac{100\%}{precipitation}$$

where the three urban water balance components evapotranspiration *ev*, infiltration *ri* and surface runoff *rs* are pairwise compared to their “natural” value. The obtained value is expressed as a number between 0 and 100 %. The choice of a natural reference is subject to discussion: currently, the natural water balance is calculated with ABIMO, by changing all areas to unpaved, and by setting the land use type to “Forest”.
A first application for Berlin by Guericke, et al. (2023) shows that urbanization leads to an increase in surface runoff and a decrease in evapotranspiration. We could observe, that infiltration is similar in both urban and natural scenario: In one case, the paved and sealed surfaces increase the runoff and hinder the infiltration, in the other the vegetation promotes transpiration preventing water to percolate. Given these results, we suggest using ΔW as an indicator for identifying those areas that could profit the most from the implementation of storm-water management measures / water-sensitive urban design (WSUD), e.g., in terms of heat stress reduction or flood prevention.

**Model Validation and Sensitivity Analysis**

Performing a validation of the model at city level is challenging, as evaporation and ground-water recharge can hardly be measured. For the surface runoff component of the water balance, a validation for about 100 $km^2$ of impervious area was possible by comparing the predicted runoff with the measured amount of stormwater reaching the waste-water treatment plants (WWTP) in Berlin from the combined sewer system and simulated combined sewer overflows (CSO). WWTP data from 2007 to 2021 was used for this purpose (unpublished measurements by Berliner Wasserbetriebe, 2022).
Model sensitivity to variations in climate was tested by running ABIMO for 1992-2019 using real climatic data.

**Model adaptation**

Since its presentation by Guericke, et al. (2022) ABIMO has been further developed in several aspects. On one hand, roads are now simulated as a feature separate from other parcels (e.g. housing blocks, parks).
On the other hand, transferability of the model has been investigated: The structure of the input data of the original model strongly reflects the Berlin application, with certain parameters organized in the same categories used by the city. Currently, we are working on restructuring and refactoring ABIMO to make it more easily applicable to other cities. To achieve this, we are utilizing data provided by the city of Cologne.
Since each city collects data differently, gathering and interpreting data can be challenging.
For example, in Berlin, the "yield-class" parameter, which defines the quantity and quality of vegetation, is derived as an assumption based on the area's use and urbanization type. In the case of Cologne or other cities, where this categorization is missing, we propose using the Normalized Difference Vegetation Index (NDVI) that can be easily calculated from satellite imagery's near-infrared and red wavelength data, providing an alternative approach.

## Results and discussion

**Validation**

The simulated annual runoff from the area with combined sewer system for different climatic years is in good agreement with the annually measured surface runoff with a mean absolute percentage error (*MAPE*) of 5.89 % (Figure 1). A second validation approach was investigated by comparing ABIMO’s results with the runoff calculated with the modelling software InfoWorks for the district of Berlin I (a specific portion of the Kreuzberg district), obtaining first promising results.

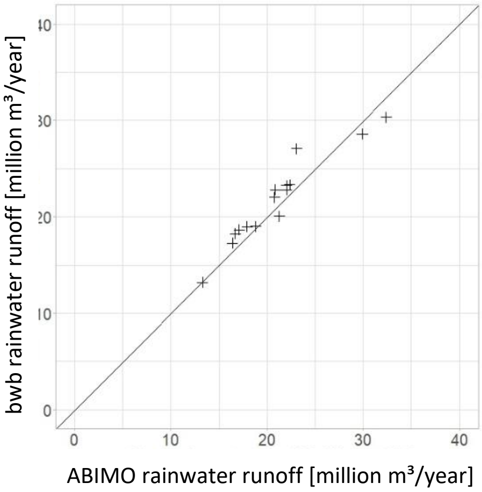


**Figure 1 -** Validation of the surface runoff component calculated for Berlin by the model ABIMO using WWTP data provided by Berliner Wasserbetriebe and simulated data of the combined sewer overflows

**Climate sensitivity**

Figure 1 also shows a high sensitivity to differing climates for the runoff component of the compared years 2007 to 2021. The same is true for all three components, as is shown for the years 1992-2019 in **Fehler! Verweisquelle konnte nicht gefunden werden.**. For instance, in a wet year (such as 2017) with precipitation > potential evaporation we find high infiltration above 30% and evapotranspiration just above 40%. In a dry year (such as 2018), relative evapotranspiration increases to 60% at the expense of infiltration. However, while ABIMO shows high sensitivity to climatic input data, the deviation ΔW is almost constant for different climatic scenarios if land use remains the same. This indicates that ΔW may be a robust indicator of anthropogenic impact on the water balance and could even be comparable between cities in different climate areas, such as Berlin and Cologne.

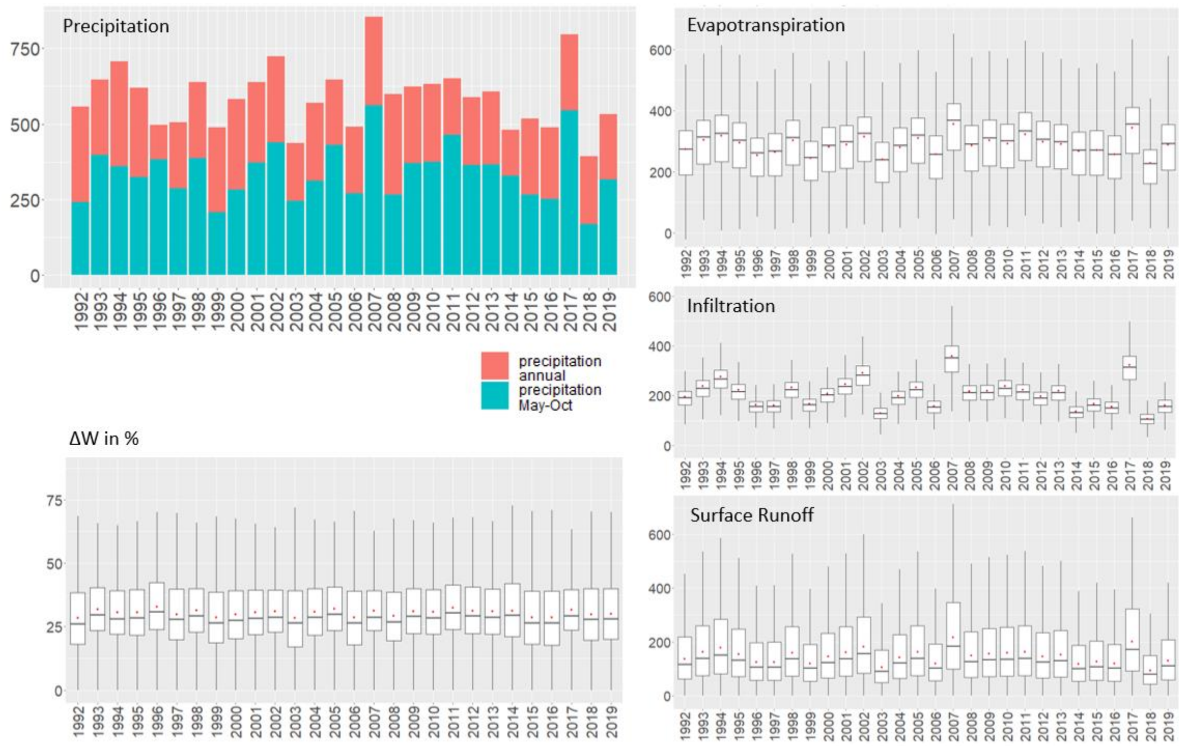


**Figure 2 -** Sensitivity of the simulated water balance components (in mm/year) and ΔW (in %) towards climatic change, obtained using real precipitation measurements from the years 1992 to 2019 for Berlin

**Transferability**

First results were obtained for the city of Cologne, demonstrating the transferability of ABIMO, while highlighting the challenges presented when using input data from different cities. To facilitate the transfer to other cities a generalisation of the model's input parameters hast been performed, reducing redundancies and removing unused parameters. This process allowed us to recognize limitations as well as address and correct errors in the original source code. The aforementioned approach of replacing the Yield-Class with NDVI values gathered from satellite imagery has shown first promising results (Figure 3).

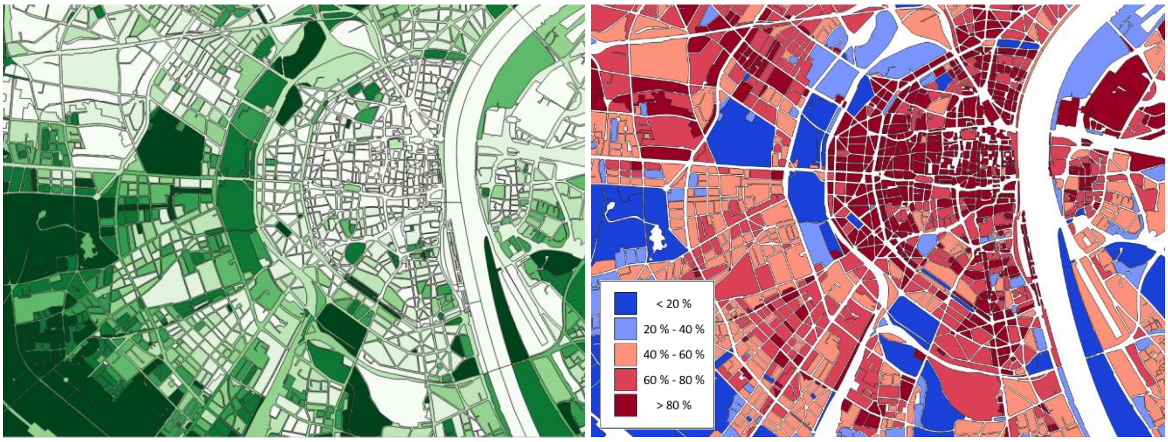


**Figure 3 –** NDVI mean values per block-area computed for the city of Cologne from open satellite Data (on the left) and deviation from the natural water balance ΔW (on the right)

## Conclusions and future work

The open-source Water Balance Model ABIMO is capable of estimating the components of the water balance - evapotranspiration, surface runoff and infiltration - for urban areas. ABIMO has been validated and tested for its original application in the city of Berlin.

In order to facilitate transferability, a restructuring of ABIMO's source code has been carried out. The model was applied to the Cologne case study, obtaining promising results.

A parameter ΔW was defined to describe the deviation of the water balance from its natural reference scenario. ΔW can be used to indicate the need for blue-green-infrastructures to mitigate the effect of extreme climatic events.

One major future development will be the integration of measures of WSUD, such as green-roofs and infiltration systems, into the model, in order to correctly simulate the status quo with existing and planned blue-green-infrastructures on the urban water balance.

Within the scope of the German national research project AMAREX, the model ABIMO will be made accessible to planners through an online web-tool.

## Acknowledgements

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The Water Balance Model ABIMO calculates the water balance components **evapotranspiration**, **surface runoff** and **infiltration** in the urban environment on **spatially separated block areas**, each of them having specific input data, such as land use, vegetation, types of pavement and amount of buildings.
The model relies **on long-term average precipitation and potential evaporation** data.

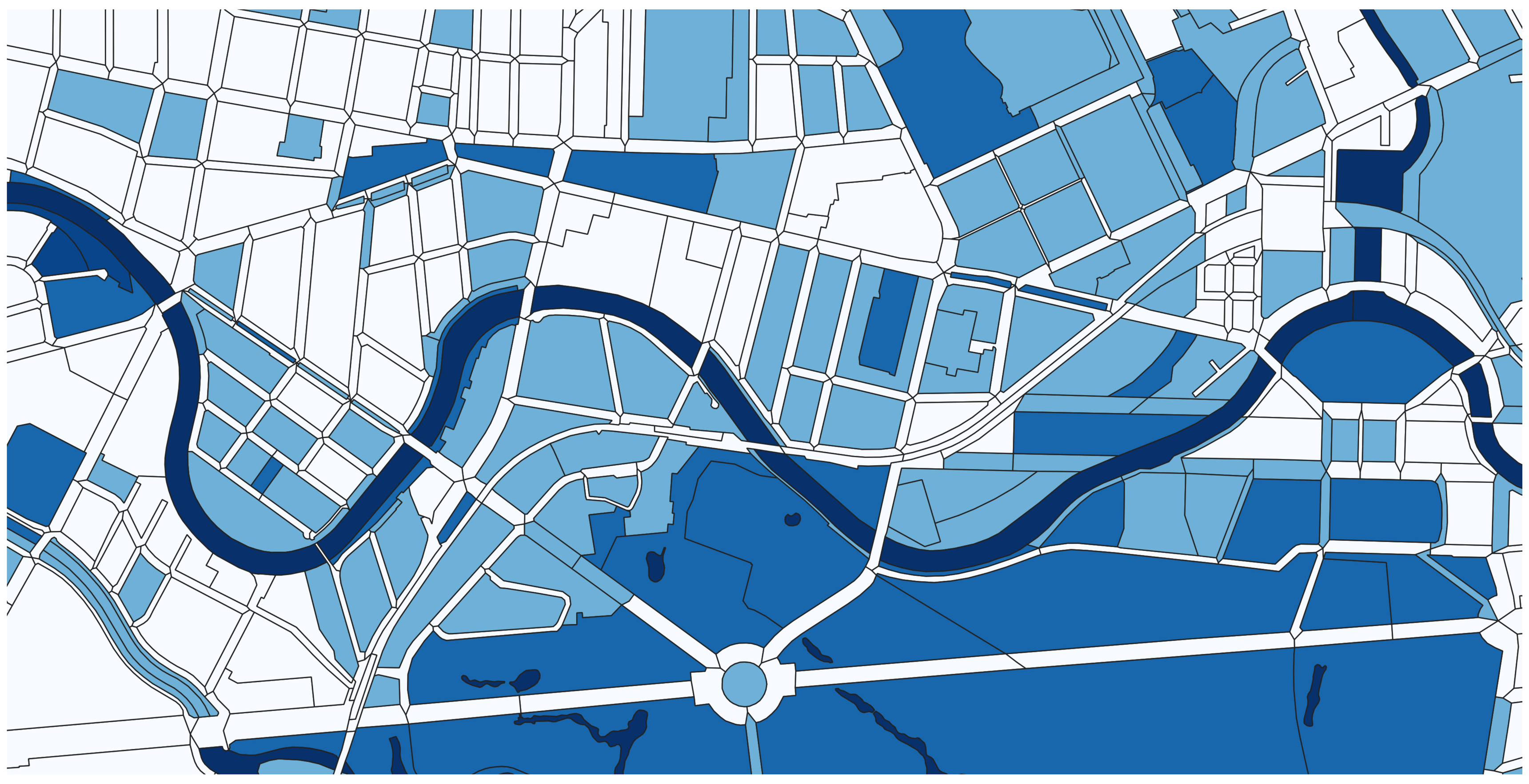

*Figure 1 – Evapotranspiration Levels in Berlin: ABIMO Model Results*

## Adaptation and Transfer

ABIMO has been translated from C++ into the R programming language obtaining improved clarity and adaptability. Some of the major changes are:

- Integration of **urban water sensitive design measures**
- Correction of inconsistencies in the original code
- Generalization of the code for better **transferability**

The new code has been tested on the city of Cologne.

## Validation

Two validation approaches were adopted comparing ABIMO's runoff component with (1) WWTP stormwater measurements and (2) simulated data obtained with the hydrodynamical model InfoWorks for one catchment in Berlin.

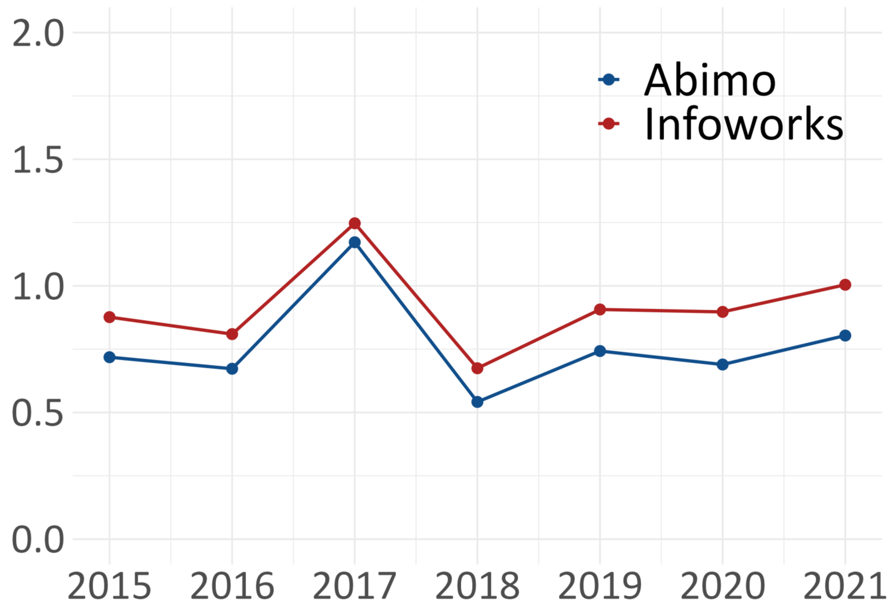


*Figure 2 – Validation: runoff in million m³, ABIMO vs. InfoWorks*

## Natural Water Balance

The German Water Association recommends minimizing **deviation from natural water balance** in development projects to promote local infiltration and evaporation while reducing runoff. ABIMO can be used to easily calculate the water balance in natural scenarios, e.g. by removing pavements and increasing vegetation.

A parameter **ΔW** was introduced to quantify the deviation between natural (*nat*) and urban (*urb*) water balance as:

$$\Delta W = \frac{1}{2}(|ev_{nat} - ev_{urb}| + |ri_{nat} - ri_{urb}| + |rs_{nat} - rs_{urb}|)\frac{100\%}{P}$$

being $P$ the precipitation and $ev$, $ri$, $rs$ the three water balance components respectively.

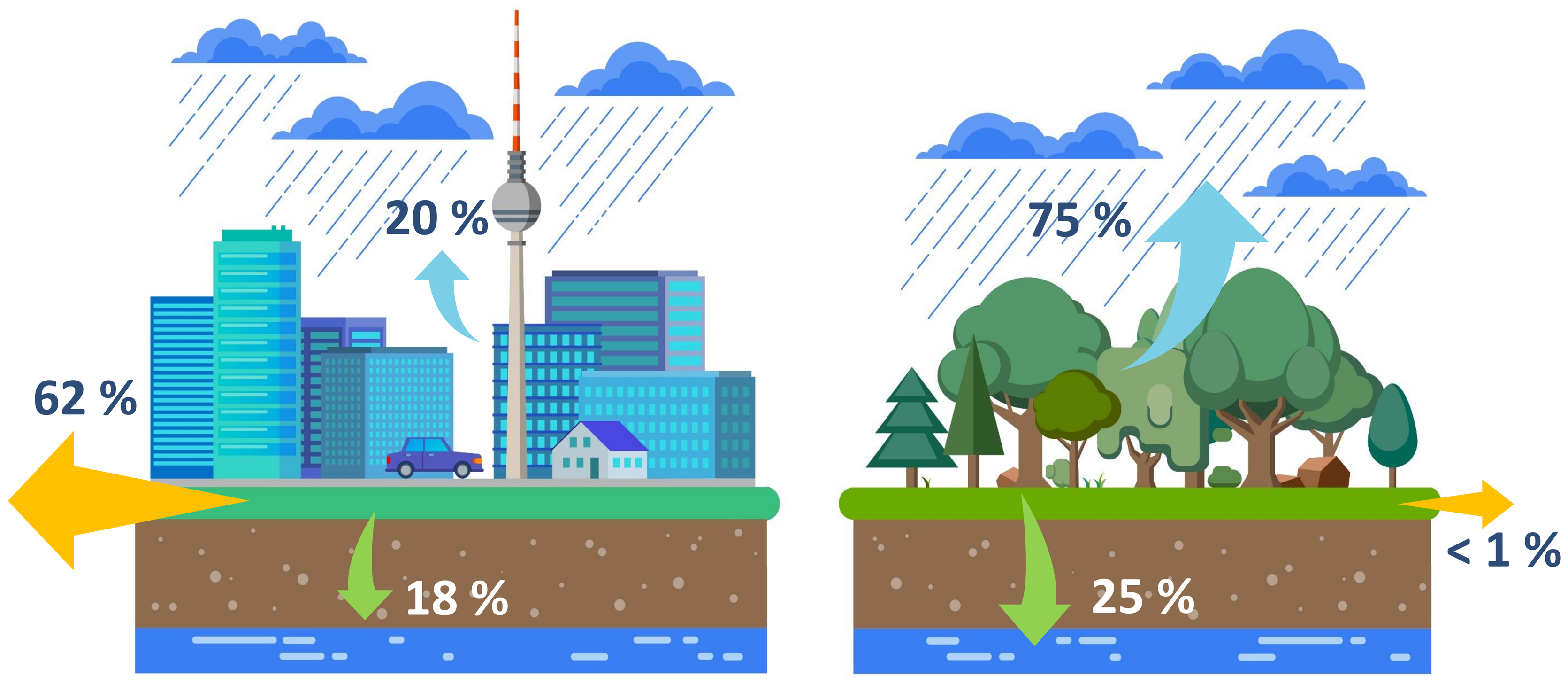


*Figure 3 – The water balance in urbanized vs. natural scenario*

*Can ΔW identify areas prone to intense effects from extreme weather?*

## Conclusions and Outlook

The ABIMO model reliably calculates the water balance of urban areas and can be adapted to other cities with proper input parameters.

A **new R-based version** will soon be available, offering a more intuitive and flexible use. Further steps include calibrating USWD features and investigating ΔW for stormwater management needs.

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*amarex.de* *GitHub*

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