Adapting weighing-bucket rainfall observations to urban applications

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Highlights

- Data collection and processing approach for 1-minute rain values from weighing buckets.
- Noise is removed from the record, without affecting event rainfall totals.

Introduction

Urban drainage modelling requires measurements of rainfall at small temporal scales (e.g. Berne et al., 2004; Ochoa-Rodriguez et al., 2015). Rainfall gauges used for these measurements have typically been of the tipping bucket type. Some challenges when using tipping bucket gauges in the field are that (1) the funnel may get clogged, (2) there will be some losses between tips (i.e. unregistered rainfall), which increase with higher rainfall intensities, and (3) that there is no way to check (without using an additional rainfall collector) the total amount of precipitation over a given time period. For best results tipping bucket gauges therefore require calibration to correct rainfall intensities and regular field visits to remedy clogging. Even then clogging remains hard to predict and may result in data unavailability.

Weighing bucket rain gauges provide an alternative with less-frequent maintenance requirements (Geonor AS, 2015). These devices have a larger opening (typically 200 cm^2, thus avoiding clogging) that collects precipitation into an enclosed bucket. This bucket is continuously weighed to measure the accumulated precipitation, and the accuracy of the sensor can be checked by adding known weights into the bucket (e.g. Broekhuizen, 2019; Duchon, 2008). Rainfall rates are obtained from the increase in accumulated precipitation over a certain time interval. For large time intervals (e.g. one hour) this is relatively straightforward, as many repeated measurements can be made at the end (e.g. during the last 5 minutes) of each period to reduce influence from measurement noise. However, for the small temporal scales needed for urban hydrological applications (e.g. 1 minute), it is not as straightforward to process the signal while distinguishing between noise of the measurement signal and actual rainfall. Therefore the goal of this paper is to propose a practical procedure for obtaining 1-minute rainfall rates from a weighing bucket precipitation sensor, where noise (Figure 1) is removed and the rainfall totals are unaffected.

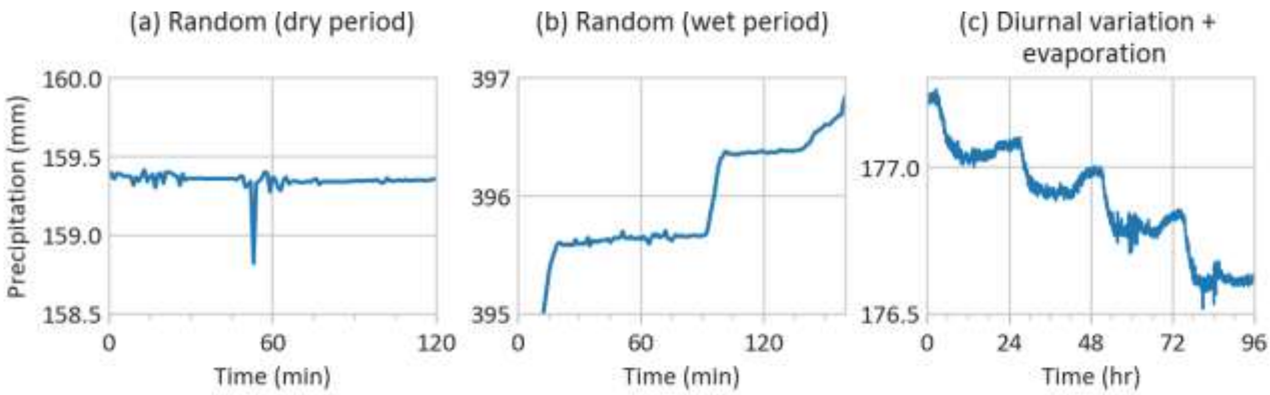

Figure 1. Examples of noise found in the raw sensor data: (a) random noise values with occasional spikes; (b) random noise during rainfall; (c) diurnal patterns and some evaporation (reduction of rainfall total) during dry periods, random noise is visible too.

Methodology

Sensor installation and maintenance

A Geonor T200B weighing bucket (Bakkehøi et al., 1985; Geonor AS, 2015) installed in Luleå, Sweden, was used for this study. A Campbell Scientific CR200 (until April 2018) and a Campbell Scientific CR1000 were used to log the data. Apart from short visual inspections, maintenance was limited to emptying the gauge twice a year (before and after winter). On these occasions the performance of the gauge for accumulated precipitation was found to be accurate within ±1% (Broekhuizen, 2019). On both occasions, a layer of mineral oil is added to reduce evaporation, and before winter, antifreeze is added to melt snow. Since the sensor is weight-based snowfall is measured too; however, in in this paper the focus is on rainfall since the main challenge for snowfall would be accounting for the increased wind-related under catch.

Data collection and processing

The electronic signal from the sensor has a frequency (f) which increases from approx. 1050 Hz (empty bucket) to approx. 3000 Hz (full bucket), with a manufacturer calibrated formula to convert to accumulated precipitation (P_A). Special efforts were undertaken since 2016 to improve the data quality, so several logging approaches were tested. The current procedure is as follows:

1. Every 2 seconds, take a 1-second average of f and convert to P_A using the manufacturer's equation. Keep the 150 most recent readings (i.e. 5 min) in memory.
2. At the end of each minute, store the median of the last 5 readings of P_A (i.e. median over 10 s).
3. For each minute, calculate M_w, the median of P_A for two time windows w_1 (length discussed below) and w_2 (48 hours); and Δ_{48}, the increase of M_{w2} in a 3-hour window; all windows centred on that minute.
4. Minutes where $\Delta_{48} \geq 0.2$ mm are considered as wet, other minutes as dry.
5. For wet minutes the rainfall rate $P = M_{w1}$, for dry minutes $P = 0$.

In step 3, the use of window w_1 (scale of minutes to a few hours) aims to filter out small random noise, the use of window w_2 (48 hr) aims to filter out diurnal variations; step 4 aims to exclude any noise from dry periods. The choice of w_1 is critical for the procedure, so multiple values were tested. The goal was to find a balance between excluding measurement noise (e.g. negative values for P) while matching total rainfall volume (i.e. the increase in P_A) over rainfall events or other time periods.

Results and discussion

Steps 3 and 4 above proved well-able to distinguish between wet and dry periods, thereby ignoring the noise in dry periods (see Figure 2), without also discarding small increases in wet periods that could be actual rainfall. This information can also be used to identify rainfall events from the continuous record.

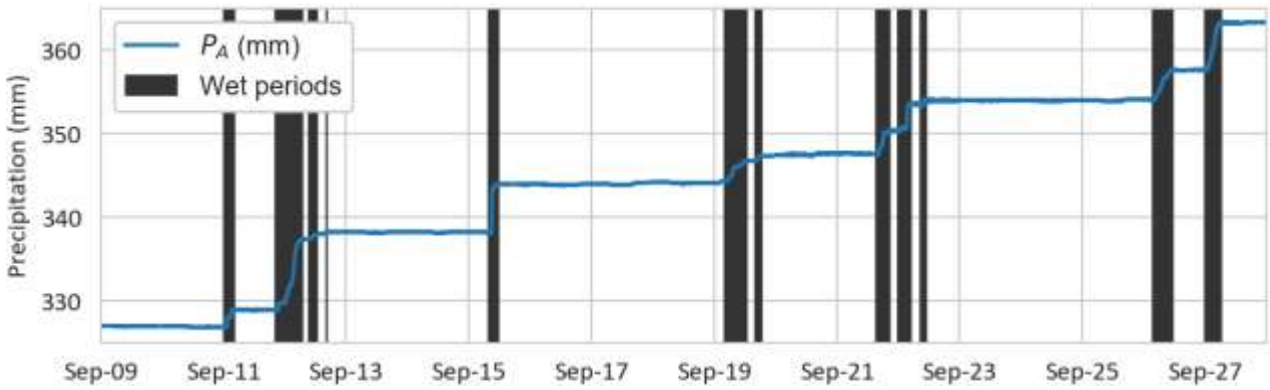

Figure 2. Example of identification of dry and wet periods based on long-term increase in accumulated precipitation. The noise that is visible in dry periods will be ignored.

To assess the accuracy of the proposed method for different values of w_1, rainfall event volumes were examined: the sum of the calculated 1-minute rates (ΣP) should match the increase in accumulated precipitation in the bucket (ΔP_A), see Figure 3. Negative values of P were removed, since they should logically not occur in rainfall records and could cause problems when used in e.g. model inputs. It is clear that simply summing the raw minute values (i.e. $w_1 = 1$) would result in overestimating the accumulated rainfall, since the negative values have to be removed from the 1-minute time series. If the value of w_1 is too high (e.g. 12 h) the smoothing operation removes some rainfall around the start and end of events, resulting in an underestimation of event rainfall. Values for w_1 of 2 to 4 h gave good results for the current dataset, with only small differences between ΣP and ΔP_A.

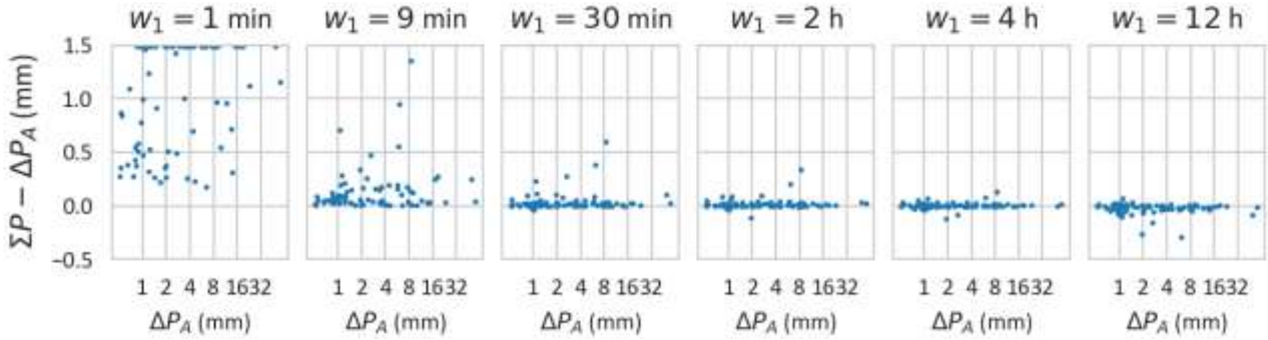

Figure 3. Errors in event total rainfall for different values of w_1. ΔP_A is the increase in accumulated precipitation during the event, ΣP is the sum of 1-minute rainfall rates calculated for different values of w_1. Notes: (1) errors for $w_1 = 1$ min were capped at 1.5 mm, but extend to > 10 mm; (2) logarithmic scale on the x-axis.

The ability to compare calculated 1-minute values with totals from the same instrument is one of the key benefits of weighing bucket rain gauges. Another is that if failure of the measurement equipment causes gaps in the record, the rain is still accumulated in the gauge so some idea of rainfall during the period may still be gained. Finally, calibration of the sensor itself requires only adding known weights into the bucket, so a simple scale is all the equipment that is required, and the calibration can be carried out in the field.

Conclusions and future work

Weighing bucket rain gauges have some advantages over tipping bucket gauges (no clogging so fewer site visits; no splashing or tipping losses; rainfall is accumulated allowing for checks), but require additional data processing to obtain reliable one minute observations. This paper proposed a data processing method that:

- Removes signal noise during both wet and dry periods;
- Does not cause errors in total event rainfall;
- Makes weighing-bucket rain gauges more applicable for the short time steps needed in urban hydrological applications.

Future work could consider using multiple sensors in the same gauge for more robust measurements (Duchon, 2008). The running record of recent readings (step 1 in the procedure) can also be used to obtain e.g. 5-minute or 15-minute observations (with more repeat readings for higher precision) and check if the obtained 1-minute observations are consistent with these. Finally, the proposed method may also be applicable for converting accumulated runoff from e.g. pilot scale green roofs to time series of runoff rates.

References

Bakkehøi, S., Øien, K., & Førland, E. J. (1985). An Automatic Precipitation Gauge Based on Vibrating-Wire Strain Gauges. Hydrology Research, 16(4), 193–202. https://doi.org/10.2166/nh.1985.0015

Berne, A., Delrieu, G., Creutin, J.-D., & Obled, C. (2004). Temporal and spatial resolution of rainfall measurements required for urban hydrology. Journal of Hydrology, 299(3–4), 166–179. https://doi.org/10.1016/j.jhydrol.2004.08.002

Broekhuizen, I. (2019). Uncertainties in rainfall-runoff modelling of green urban drainage systems: Measurements, data selection and model structure [Licentiate thesis, Luleå University of Technology]. http://urn.kb.se/resolve?urn=urn:nbn:se:ltu:diva-73367

Duchon, C. E. (2008). Using vibrating-wire technology for precipitation measurements. In S. Michaelides (Ed.), Precipitation: Advances in Measurement, Estimation and Prediction (pp. 33–58). Springer.

Geonor AS. (2015). Manual for T-200B series precipitation gauge. http://geonor.com/live/products/weather-instruments/t-200b-weather-precipitation-rain-gauge/

Ochoa-Rodriguez, S., Wang, L.-P., Gires, A., Pina, R. D., Reinoso-Rondinel, R., Bruni, G., Ichiba, A., Gaitan, S., Cristiano, E., van Assel, J., Kroll, S., Murlà-Tuyls, D., Tisserand, B., Schertzer, D., Tchiguirinskaia, I., Onof, C., Willems, P., & ten Veldhuis, M.-C. (2015). Impact of spatial and temporal resolution of rainfall inputs on urban hydrodynamic modelling outputs: A multi-catchment investigation. Journal of Hydrology, 531, 389–407. https://doi.org/10.1016/j.jhydrol.2015.05.035