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EVALUATION OF THE *DISCHARGEAPP*: A SMARTPHONE APPLICATION FOR DISCHARGE MEASUREMENTS

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ABSTRACT

The design of optimal policies for water resources management and for flood risks mitigation needs hydrometric quantities such as water level and discharge. In many regions of the world, traditional measurement methods for water levels and discharge are not in use because of their acquisition and maintenance costs. Thus, there is a lack of cost-effective, easy to use and vandalism-free technologies. Smartphone-based applications may close this gap, such as the *DischargeApp* (www.discharge.ch), a smartphone-based application water level, surface velocity and discharge in open channels. This paper presents a study that evaluates the *DischargeApp* to gauge water flow rates at 20–120 L/s in a clear water laboratory flume. In comparison to gauges of a magnetic flow meter the resulting absolute measurement error shows to be ±10 L/s, while for more of 85% of the measurements, the relative error is below 15%. This acceptable error, together with its simplicity and low cost characteristic, rank the *DischargeApp* as an ideal device for fast measuring of discharges. The *DischargeApp* has, therefore, the potential to gather useful and much needed hydrometric data in order to globally improve water resources management.

Keywords: Flow, Water Level, Discharge Measurement, Smartphone, Measurement Error

1. INTRODUCTION

In many regions of the world, climate change is further increasing the pressure on fresh water resources while, at the same time, the frequency of flood events is noticeably growing. Hydrometric data such as water level and discharge time series are key variables for the design of policies to tackle these two issues. However, such type of data are lacking, especially in emerging economies, often due to the high costs for investment, operational and maintenance of traditional hydrometric methods. At the same time, the capabilities and availability of smartphones in all regions of the world are continuously increasing. This is making them an ideal tool for being used as measurement devices. Additionally their simplicity of operation makes it ideal not only to be used by experts but also by untrained citizens (Le Coz, Patalano et al. 2016, van Meerveld, Vis et al. 2017, Etter, Strobl et al. 2018).

In this study, we evaluate the *DischargeApp*, a smartphone-based measurement device. It is an Android application, which optically measures open channels' water level and surface velocity and derives the discharge thereof (Lüthi et al., 2014). The *DischargeApp* makes use of the smartphone's built-in camera and accelerometer. It uses the patented Surface Structure Imaging Velocimetry (SSIV) technique (Peña-Haro et al., 2015; Leitão et al., 2018; Lüthi et al., 2018, Peña-Haro et al., 2018). The SSIV is a correlation-based technique typically applied to large channels or rivers, similar to other Large Scale Particle Imaging Velocimetry (LSPIV) approaches (Fujita et al., 1998; Muste et al., 2008; Detert and Weitbrecht 2015).

There is a need to investigate the errors and reliability of flow measurements obtained with the *DischargeApp*. Therefore, flow measurements are performed in a laboratory flume for a range of flow rates extending from 20–120 L/s under controlled conditions. These flow rates and the channels' cross sections closely resemble the situation in lined irrigation channels all over the world. Measurements were taken simultaneously at two different downstream positions. At one position the phone was mounted on a tripod (*tripod* site) and at the other position the phone was hand-held (*hand-held* site). This allows to study how the accuracy of the measured discharge is decreased by small shifts and shakes during the recording in hand-held mode – as it would typically occur in the field without having a tripod-fixed camera position. Furthermore, it allows to cross-check the technique's robustness to be applied at different cross section and illumination conditions.

2. MATERIAL AND METHODS

2.1 Experimental Approach

Measurements were conducted at the Laboratory of Hydraulics, Hydrology and Glaciology (VAW), ETH Zurich, Switzerland, in a 25 m long trapezoidal flume as shown in Figure 1A. Detailed descriptions can be found in Friedl et al. (2018; 2019). The flume is made out of impermeable cement mortar and its bed contains natural grains with a diameter of 4 mm. For the experiments presented here, the effective Manning-Strickler coefficient was determined to be at 68±1 $m^{1/3}/s$. In order to be as close as possible to steady state conditions, measurements were performed at the downstream area of the trapezoidal flume at the end of a straight channel of about 7 m length. Two different sites were configured, the *hand-held* and the *tripod* sites. Photographs illustrating their locations are given in Figure 1 (B+C).

In order to configure the sites, it is necessary to measure and enter the coordinates of the Ground Control Points (GCPs) and the bathymetry. Schematics of the GCs for the *hand*-held and tripod sites are shown in Figure 2. The *DischargeApp* requires the input of four GCPs. Combined with the smartphone's accelerometer data, they allow to later determine the exact 3D position and orientation of the smartphone during the video recording. This information, in turn, allows to register and map the water surface image frames from 2D pixel space to 3D metric space. The bathymetry and GCPs were surveyed using a *Disto S910* (*Leica*), a laser distance measurer allowing to capture positions in three-dimensions from one single location.

Several measurements were performed with a *SAMSUNG Galaxy S5 (SM G900F)* at the *tripod* site and with a *Fairphone 2* at the *hand-held* site. The measurements were performed for a range of seven different flow rates, with an average discharge determined by a Magnetic Induced Discharge (MID) flowmeter to [19.6, 30.1, 39.7, 59.8, 79.9, 98.7, 118.3] L/s. For every of these flow rates, three to five measurements were performed at both sites.

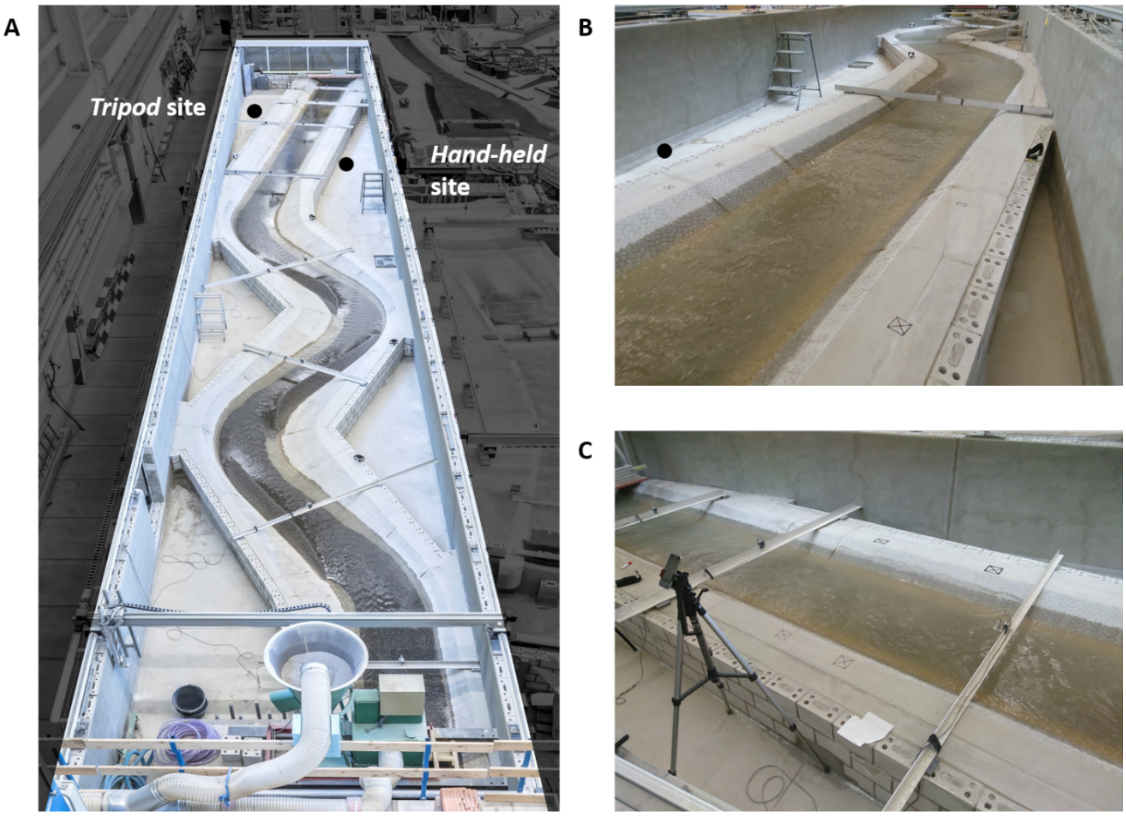

Figure 1. (A) Illustration of the 25 m long flume used in this study. Flow direction is from bottom to top. Two black dots mark the positions of the *DischargeApp* users during their video recordings. (B) The *hand-held* site with the location of the user during the movie recordings indicated by the black dot. (C) The *tripod* site with tripod and smartphone used for the measurements, where also the four GCPs can be seen, which are marked by black crosses inside black rectangles on the shorelines of the flume. (Photos printed with courtesy of Andreas Schlumpf, VAW.)

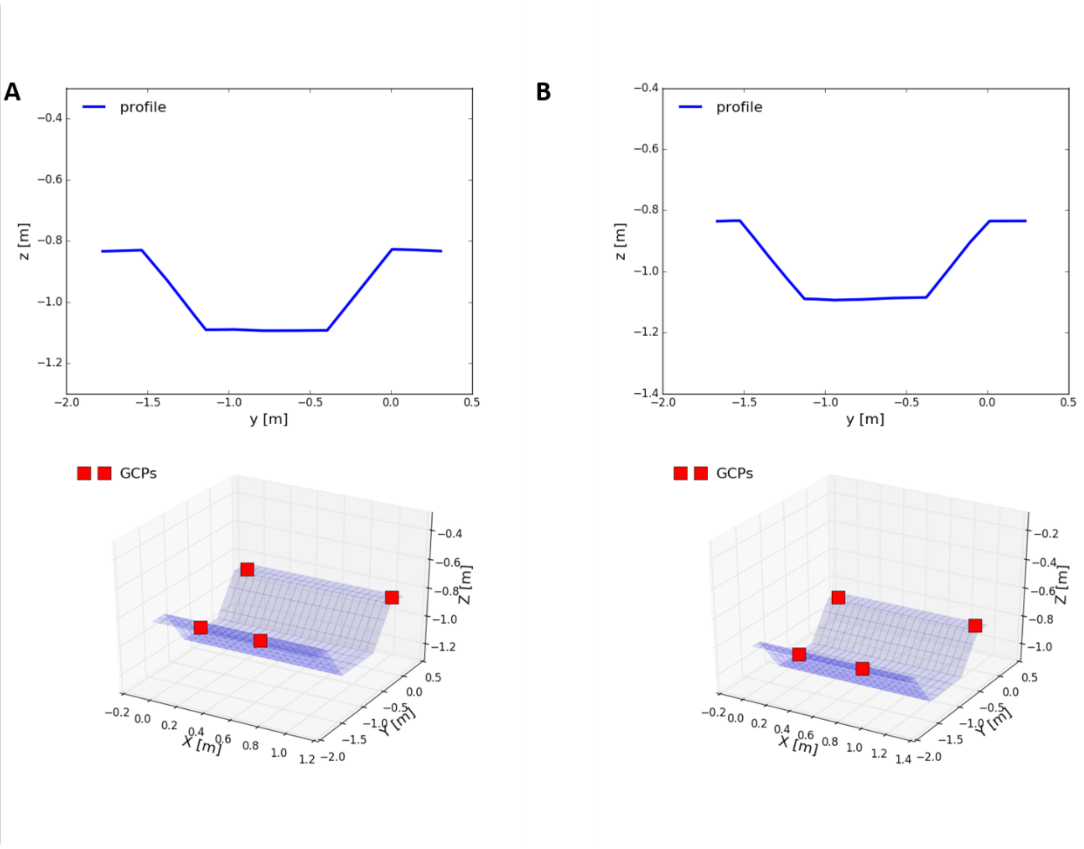

Figure 2. (A) Schematics for the *hand-held* site, with (top) 2D cross-section and (bottom) 3D cross-sectional view with the extruded bathymetry and GCPs (markers) and shoreline. (B) Schematics for the *tripod* site with same information as in (A).

2.2 Data Processing

The *DischargeApp* has a Graphical User Interface (GUI), which guides the user through the main steps of performing and analyzing the video recordings (Figure 3). The first step is site selection and configuration (Figure 3A). Next, a 5 s recording is to be performed. After this, the user is required to define the positions of the GCPs on a stillframe of the video in image (pixel) coordinates as shown in Figure 3B. This information is initially used to register the camera in 3D, i.e. to compute the camera extrinsic parameters. The rest of the registration work is done in the background by applying information relative to the orientation of the smartphone as obtained by its accelerometer during the video recording (Lüthi et al., 2014). The next step is to manually define the intersection between water surface and shoreline to define the actual water level. As the camera is already registered in 3D coordinates from the previous step, this value is shown on the phone screen in metric units (Figure 3C). Finally, the patented SSIV algorithm (Leitão, Peña-Haro et al. 2018, Lüthi, Philippe et al. 2018) is applied to the image sequence, which is processed locally on the smartphone. Exemplarily the surface velocity field and the derived discharge are displayed in the screenshot given in Figure 3D.

Location
47°24'36"N 8°30'19"E
Direction
4 km, NNW (340.86°)
Profile
Profile points (y, z)
15 points defined
Roughness
70.0

Water column height
Water column 7.60 cm
Estimated discharge 17.54 L/s

Measurement results
Water column 7.60 cm
Velocity 0.39 m/s
Discharge 19.41 L/s

Figure 3. Four main steps required to apply the *DischargeApp*. (A) Site selection and configuration. (B) After the video recording, manual definition of the location of the ground control points. (C) User guided determination of the actual water level. (D) Results obtained after measuring the water level, the surface velocity field and after processing the data to compute the discharge.

The approach how discharge is computed from water level, surface velocity field and further information is described in detail in the following: It is assumed that the cross-section of the flume is prismatic over the field of view considered. This allows to fit a 2D streamwise surface velocity profile to the time averaged stream wise velocity components. Following the approach presented by (Absi 2006), the vertical velocity profile is computed over the spanwise direction using a mixing length model. Here, only the streamwise surface velocity and a roughness length derived from the Manning-Strickler coefficient are needed as input parameter. For a typical setup, the time required for the whole procedure including movie recording and data processing is less than two minutes per measurement.

3. RESULTS AND DISCUSSION

The measured water levels for the *hand-held* and the *tripod* sites are shown in Figure 4, both plotted against the MID discharge values (Figure 4A) as well as against the *DischargeApp* data (Figure 4B). Power law fits of quasi rating curves were computed in a least-square sense as functions of the optically measured water levels using functions of the form:

$$Q=\alpha\left(h-b\right)^{\gamma} \qquad [1]$$

with Q = discharge, h = water depth, and α, β, γ different fit-parameters. The power-law fits obtained for both sites are slightly different, reflecting the marginally different cross-sectional geometries of the rough bed at the two downstream locations. Overall, the scatter of the data points around the rating curves is quite small, indicating that the water level measurements give reliable results.

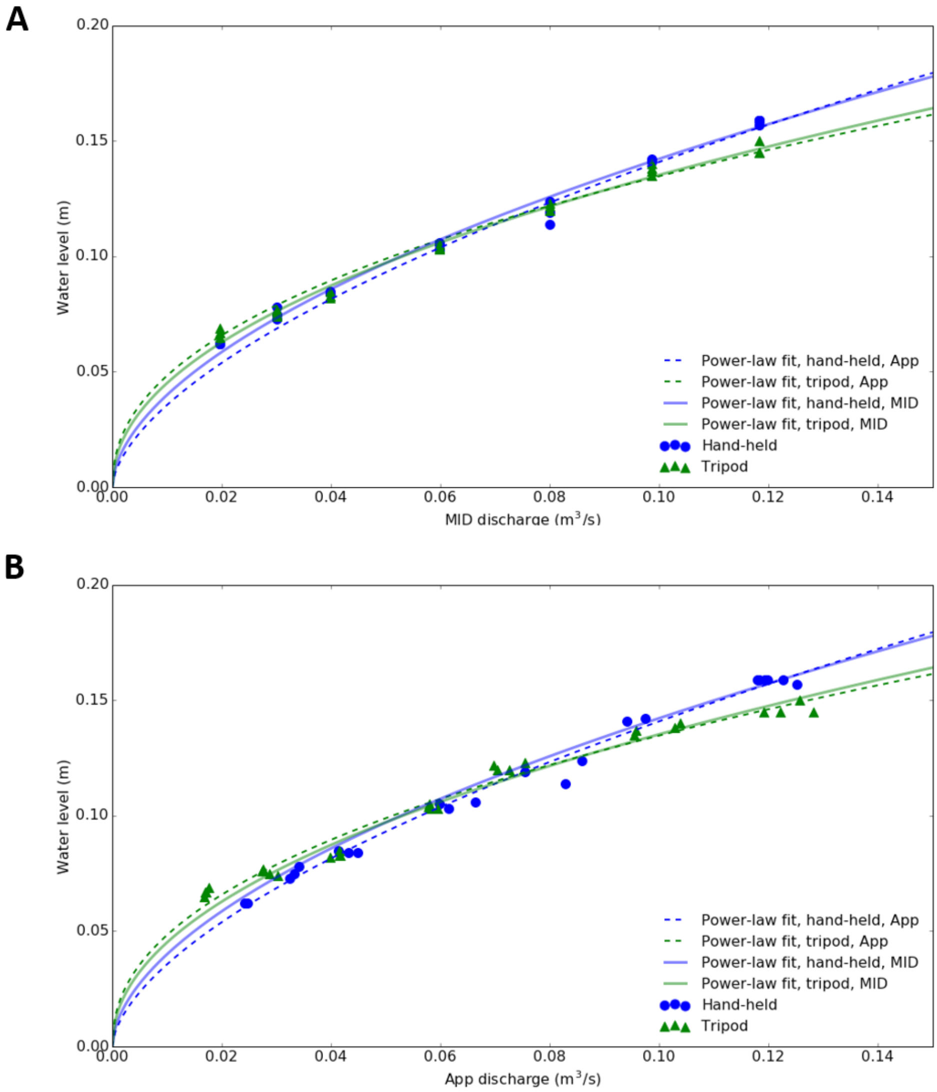

Figure 4. Optically measured water level plotted against discharge measurements for movie recording at the *hand-held* site and the *tripod* site. Lines represent rating curves obtained empirically in a least-square sense. (A) Water level plotted against flow rate measurements by MID. (B) Water level plotted against flow rate measurements by *DischargeApp*.

In Figure 5A, all app-based discharge values are plotted against their according MID discharge values. Again, the overall agreement is quite good, showing that the measurement error must be relatively small. In Figure 5B, the absolute accuracy of the discharge measured by the *DischargeApp* is plotted against their according MID discharge values. The error of all app measurements is smaller than ±10 L/s.

Figure 6 shows the distribution of the relative errors for both hand-held and tripod data sets. The relative errors are understood here as the deviation of the *DischargeApp* discharge from the MID-based discharge. All the data obtained with at the *tripod* site lie within a ±15% range for the relative error, whereas only 87% of the hand-held data lie within the same range. In 70(82)% of the cases for the *hand-held* site (*tripod* site), the relative error is within a range of ±10%. Finally, in 48(54)% of the cases, the relative error is less than 5%. The error is somewhat lower for the measurements at the *tripod* site. This indicates that hand-held movies induce a finite, but small error due to the motion of the user during the recordings.

To sum up, for the flow rates considered in this study, 100% of the tripod data and 87% of the hand-held data have an error smaller than ±15%. Except for the low flow rates at 20 L/s, the error is even lower than 10%. Additionally, there is a difference between the accuracy obtained for the hand-held and tripod measurements. The difference is, however, almost insignificant.

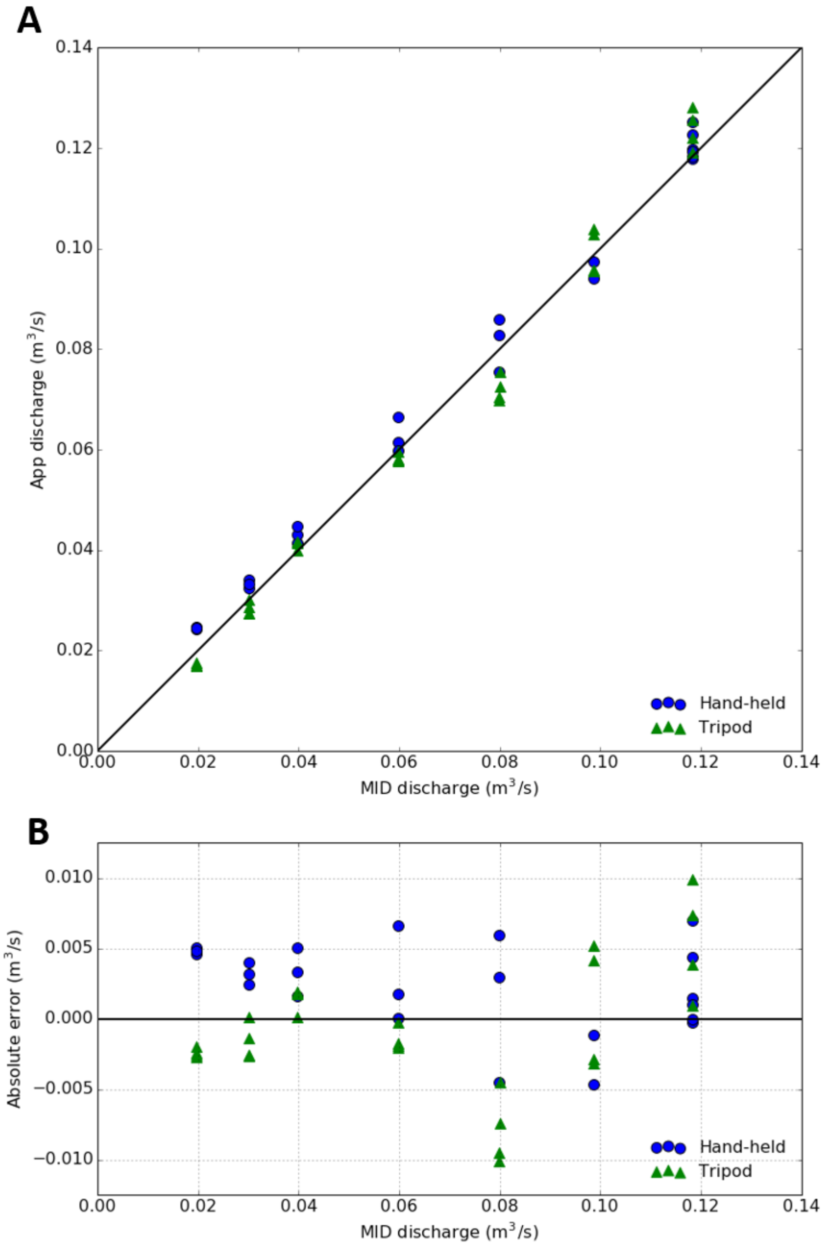

Figure 5. (A) Flow rate determined by *DischargeApp* plotted against MID measured discharge. (B) Absolute error plotted against measured MID discharge. All measurements are accurate within a range of +/-10 L/s and 85% of the measurements lie within a range of ±5 L/s.

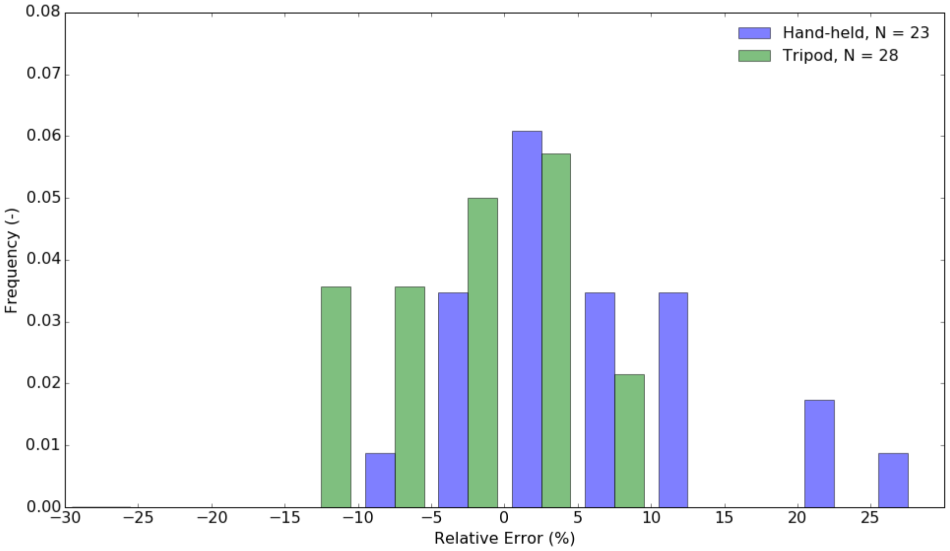

Figure 6. Distribution of the relative error of the measurements presented in Figure 5. 100% of the data obtained at the *tripod* site lie within an uncertainty range of ±15%, whereas 87% of the data obtained at the *hand-held* site lie within an uncertainty range of ±15%. Furthermore, 82(54)% of the data lie within an interval of ±10(5)% for the *hand-held* site data, whereas 78(48)% of the data lie within an interval of ±10(5)% for the *hand-held* site data.

4. CONCLUSIONS

The results presented in this study allow to evaluate the accuracy of the *DischargeApp* in a laboratory flume under controlled conditions with flow rates of 20-120 L/s. These flow rates and the two considered channel cross sections closely resemble to typical situations in lined irrigation channels all over the world. Thus, it can be assumed that the results obtained in the current study are valid for these kind of open channels as well:

It was shown, that the *DischargeApp* provides an accuracy of ±10 L/s for all conducted video recordings. The comparison performed between the accuracy of the *tripod* and *hand-held* measurements shows that the use of a tripod only marginally increases the accuracy of the measurements. Namely, 87% of the data obtained at the *hand-held site* shows an accuracy of ±15%, whereas 100% of the *tripod-site* data lies within the same accuracy range.

To sum up, the results presented in this study reveal that the smartphone-based measuring device *DischargeApp* can provide an attractive, very fast, and low-cost way to acquire hydrometric data. In forthcoming similar studies we will evaluate the accuracy of the *DischargeApp* under field conditions with larger discharge rates in the order of 1–10 m^3/s, e.g. as in sewers, in waste water facilities, or in natural rivers with heterogeneous river beds.

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