Citizen science flow - an assessment of ~~citizen science~~simple streamflow measurement methods

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Abstract. Wise management of water resources requires data. Nevertheless, the amount of streamflow data being collected globally continues to decline. ~~Involving citizen scientists to g~~Generat~~e~~ing hydrologic data with citizen scientists can ~~potentially~~ help fill this growing hydrological data gap. Our aim herein was to (1) perform an initial evaluation of three simple streamflow measurement methods (i.e. float, salt dilution, and Bernoulli run-up), (2) evaluate the same three methods with citizen scientists, and (3) apply the preferred method at a larger scale. For computation of errors, w~~W~~e used mid-section measurements from an ~~an~~ acoustic Doppler velocimeter as reference flows.~~was to (1) evaluate three potential citizen science streamflow measurement methods (i.e. float, salt dilution, and Bernoulli run-up), (2) select a preferred approach, and (3) pilot test the selected approach at a larger scale.~~ First, we (~~We~~ authors) performed 20 ~~side-by-side~~ evaluation measurements in headwater catchments of the Kathmandu Valley, Nepal~~.~~, with ~~We used mid-section measurements from an acoustic Doppler velocimeter as reference flows. Evaluated~~reference flows ~~ranged~~ ranging from ~~0.00~~6.4 to ~~0.~~240 ~~m^3~~ L s^{-1}. Absolute errors averaged 23, 15, and 37 % with average biases of 8, 6, and 26 % for float, salt dilution, and Bernoulli methods, respectively.~~Linear regressions forced through the origin for scatter plots with reference flows had slopes of 1.05, 1.01, and 1.26 with r-squared values of 0.90, 0.98, and 0.61, for float, salt dilution, and Bernoulli run-up methods, respectively.~~ Second, we evaluated the same three simple methods at 15 sites in two watersheds within the Kathmandu Valley with 10 groups of citizen scientists (three to four members each) and one "expert" group (authors). At each site, all groups performed the three simple methods, while "experts" also performed reference flow measurements (ranging from 4.2 to 896 L s^{-1}). For float, salt dilution, and Bernoulli methods absolute errors averaged 41, 21, and 43 % for "experts" and 63, 28, and 131 % for citizen scientists, while biases averaged 41, 19, and 40 % for "experts" and 52, 7, and 127 % for citizen scientists, respectively. Based on these results, we selected ~~After selecting the~~ salt dilution ~~method~~ as the preferred ~~approach~~method.~~, w~~ Finally, we performed larger scale pilot testing in week-long pre and post-monsoon ~~a one-week~~ Citizen

Science Flow ~~campaign (CS Flow)~~ campaigns involving ~~20~~ 25 and 37 ~~volunteers~~citizen scientists, respectively. Observed flows (n = ~~145~~131 pre-monsoon; n = 133 post-monsoon) were distributed among the 10 headwater catchments of the Kathmandu Valley and ranged from 0.4 to 425 L s^{-1} and ~~0.0004~~1.51 to ~~0.425~~1804 L s^{-1}~~m^3 s^{-1} and were distributed among the 10 headwater catchments of the Kathmandu Valley~~ in pre and post-monsoon, respectively.~~.~~ ~~At locations with reference flows available (n = 5), a linear regression forced through the origin between reference flows and CS Flow measurements had a slope of 0.90 with an r-squared value of 0.97.~~ Future work should further evaluate the uncertainties of citizen science salt dilution measurements, the feasibility of their application ~~applying citizen science salt dilution streamflow measurements~~ to larger regions, and the information content of additional streamflow data.~~.~~

1 Introduction

1.1 Background

~~Lord Kelvin, a 19th century Scottish physicist and mathematician, wisely said, "… the first essential step in the direction of learning any subject is to find principles of numerical reckoning and practicable methods for measuring some quality connected with it (Kelvin 1883)." With regards to our natural resources, if we aim to wisely steward them, we must first learn to measure them. While it might sound trivial, collecting and, worse yet, interpreting point measurements of precipitation, evapotranspiration, infiltration, and soil moisture at the catchment scale is fraught with challenges. Indeed, the importance of measuring streamflow is underpinned by the reality that it is the only truly integrated representation of the entire catchment that we can plainly observe (McCulloch 1996).~~

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The importance of measuring streamflow is underpinned by the reality that it is the only truly integrated representation of the entire catchment that we can plainly observe (McCulloch 1996). Traditional streamflow measurement approaches relying on sophisticated sensors (e.g. pressure transducers, acoustic doppler devices, etc.), site improvements (e.g. installation of weirs or stable cross-sections, etc.), and discharge measurements performed by specialists are often necessary at key observation points. However, these approaches require significant funding, equipment, and expertise, and are often difficult to maintain, and even more so to scale (Davids et al. 2017). Consequently, ~~Despite~~ despite growing demand, the amount of streamflow data actually being collected continues to decline in several parts of the world, especially in Africa, Latin America, Asia, and even North America (Hannah et al. 2011; Van de Giesen et al. 2014; Feki et al. 2016; Tauro et al. 2018). Specifically, there is an acute shortage of streamflow data in headwater catchments (Kirchner 2006) and developing regions (Mulligan 2013). ~~The reasons for this trend are various, but the~~This data gap ~~situation~~ is perpetuated by a lack of understanding among policy makers and citizens alike regarding the importance of streamflow data, which leads to persistent funding challenges (Kundzewicz 1997; Pearson 1998). ~~—~~This is further compounded by the reality that the hydrological sciences research community has focused much of its efforts in recent decades on advancing modeling techniques, while innovation in methods for generating the data these models depend on has been relegated to a lower priority (Mishra and Coulibaly 2009; Burt and McDonnell 2015), even though these data form the foundation of hydrology (Tetzlaff et al. 2017).

Considering these challenges, alternative methods for generating streamflow and other hydrological data are being explored (Tauro et al. 2018). For example, developments in using remote sensing to estimate streamflow are being made (Tourian et al. 2013; Durand et al. 2014), but applications in small headwater streams are expected to remain problematic (Tauro et al. 2018). Utilizing cameras for measuring streamflow is also a growing field of research (Muste et al. 2008; Le Coz et al. 2010; Dramais et al. 2011; Le Boursicaud et al. 2016), but it is doubtful that these methods will be broadly applied in headwater catchments in developing regions in the near future because of high costs, ~~and~~ lacking ~~of~~ technical capacity, and potential for vandalism. In these cases, however, involving citizen scientists to generate hydrologic data can potentially help fill the growing global hydrological data gap (Lowry and Fienen 2012; Buytaert et al. 2014; Sanz et al. 2014; Davids et al. 2017; van Meerveld et al. 2017; Assumpção et al. 2018).

Kruger and Shannon (2000) define citizen science as the process of involving citizens in the scientific process as researchers. Citizen science often uses mobile technology (e.g. smartphones) to obtain georeferenced digital data at many sites, in a manner that has the potential to be easily scaled (O'Grady et al. 2016). Turner and Richter (2011) partnered with citizen scientists to map the presence or absence of flow in ephemeral streams. Fienen and Lowry (2012) showed that citizen science text message based measurements of water level can have acceptable errors. Mazzoleni et al. (2015) showed that flood predictions can be improved by assimilating citizen science water level observations into hydrological models. Le Coz et al. (2016) used citizen scientist photographs to improve the understanding and modeling of flood hazards. Davids et al. (2017) showed that lower frequency observations of water level and discharge like those produced by citizen scientists can provide meaningful hydrologic information. Van Meerveld et al. (2017) showed that citizen science observations of stream level class can be informative for deriving model based streamflow time series of ungauged basins.

While the previously referenced studies focus mainly on involving citizen scientists for observing stream levels, we were primarily concerned with the possibility of enabling citizen scientists to take direct measurements of streamflow. Using keyword searches using combinations of "citizen science", "citizen hydrology", "community monitoring", "streamflow monitoring", "streamflow measurements", "smartphone streamflow measurement", and "discharge measurements," we found that research on using smartphone video processing methods for streamflow measurement has been ongoing for nearly five years (Lüthi et al. 2014; Peña-Haro et al. 2018). Despite the promising nature of these technologies, we could not find any specific ~~work~~ studies ~~about~~ evaluating the strengths and weaknesses of ~~how~~ citizen scientists applying these technologies ~~, equipped with modern tools like smartphones, could take streamflow measurements~~ directly in the field themselves. In fact, we could not find any studies evaluating simple streamflow measurement techniques that citizen scientists could possibly use. Therefore, ~~Instead,~~ to develop a list of potential simple citizen science streamflow measurement methods to evaluate further, we turned to the vast body of general knowledge about the collection of streamflow data.

While identifying and refining methods for citizen scientists to measure streamflow may be an important step forward towards generating more streamflow data, it

should be noted that these types of citizen science applications are not without challenges of their own. For example, citizen science often struggles with the perception (and possible reality) of poor data quality (Dickinson et al. 2010) and the intermittent nature of data collection (Lukyanenko et al. 2016). Additionally, there are other non-citizen science based streamflow measurement methods (e.g. permanently installed cameras) that may undergo rapid development and transfer of technology, and thus make a significant contribution towards closing the streamflow data gap.

1.2 Simple streamflow measurement methods considered

Streamflow measurement techniques suggested in the United States Bureau of Reclamation Water Measurement Manual (USBR 2001) that seemed potentially applicable for citizen scientists included: deflection velocity meters~~ consisting of shaped vanes projecting into the flow along with a method to measure deflection~~; the Manning-Strickler slope area method ~~whereby the slope of the water surface in a uniform reach is measured and combined with the Manning formula~~; and pitot tubes for measuring velocity heads. The float, current meter, and ~~and~~ salt dilution methods described by several authors also seemed applicable (British Standards Institute 1964; Rantz 1982; Fleming and Henkel 2001; Escurra 2004; Moore 2004a, 2004b, and 2005; Herschy 2014). Finally, Wilm and Storey (1944) and Church and Kellerhals (1970) introduced the velocity head rod, or what we later refer to as the Bernoulli run-up ~~method~~(or just Bernoulli) method~~, involving measurement of stream velocity heads with a thin flat plate~~. Table 1 provides a summary of these eight simple measurement methods. For the categories of (1) applicability in Nepal (specifically to headwater catchments), (2) cost, (3) required training, and (4) complexity of the measurement procedure, and score of either 1, 2, or 3 was given by the authors, corresponding with low, medium, and high, respectively. Theses scores were then summed, and the three methods with the lowest scores (i.e. Bernoulli, float, and salt dilution (slug)) were selected for additional evaluation in the field.

Table 1. Summary of simple streamflow measurement methods considered for further evaluation. Integer scores of 1 (low), 2 (medium), or 3 (high) for applicability in Nepal (especially for smaller headwater catchments), cost, required training, and complexity were given to each method. The three methods with the lowest score were selected for further evaluation. Smartphones are not included in equipment needs because it was assumed that citizen scientists would provide these themselves.

#	Method	Brief Description	Equipment Needs	Applica-bility in Nepal	Cost	Req-uired Training	Com-plexity	Total Score (4 to 12)	Selected for Evalu-ation (yes / no)
1	Bernoulli	Velocity-area method. Thin flat plate (e.g. measuring scale) used to measure velocity head. Repeated at multiple stations.	Measuring scale	1	1	2	1	5	yes

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2	Current Meter	Velocity-area method. Current meter (e.g. bucket wheel, propeller, acoustic, etc.) used to measure velocity. Repeated at multiple stations.	Current meter, measuring scale	2	3	3	2	10	no
3	Deflection Rod	Velocity-area method. Shaped vanes projecting into the flow along with a method to measure deflection, and thereby computing velocity. Repeated at multiple stations.	Deflection rod, measuring scale	3	2	2	2	9	no
4	Float	Velocity-area method. Time for floating object to travel known distance used to determine water velocity. Repeated at multiple stations.	Measuring scale, timer	2	1	2	1	6	yes
5	Manning-Strickler	Slope area method. Slope of the water surface elevation combined with estimates of channel roughness and channel geometry to determine flow using the Manning-Strickler equation.	Auto level (or water level), measuring scale	2	2	2	3	9	no
6	Pitot Tube	Velocity-area method. Pitot tube used to measure velocity. Repeated at multiple stations.	Pitot tube, measuring scale	2	2	2	2	8	no
7	Salt Dilution (Constant-rate Injection)	Constant rate of known concentration of salt injected into stream. Background and steady state electrical conductivity values measured after full mixing. Flow is proportional to rate of salt injection and change in EC.	EC meter, mixing containers	1	2	3	3	9	no
8	Salt Dilution (Slug)	Known volume and concentration of salt injected as a single slug. EC of breakthrough curve measured. Flow is proportional to integration of breakthrough curve and volume of tracer introduced.	EC meter, mixing containers	1	2	2	2	7	yes

1.3 Expanded description of selected simple streamflow measurement methods

1.3.1 ~~Based on these recommendations, the strengths and limitations discussed in the corresponding literature, and practical considerations about how citizen scientists could implement the different approaches, we selected three approaches for further evaluation: float, salt dilution, and Bernoulli run-up.~~ Float method

The float method is based on the velocity-area principle, whereby the channel cross-section is defined by measuring depth and width of n sub-sections, and the velocity is found by the time it takes a floating object to travel a known distance which is then corrected for friction losses. Total streamflow (Q) in liters per second (L s^{-1}) is calculated with Eq. (1):

$$Q = 1000 * \sum_{i=1}^{n} C * VF_i * d_i * w_i \quad (1)$$

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where 1000 is a conversion factor from $m^3 s^{-1}$ to $L s^{-1}$, C is a unitless coefficient to account for the fact that surface velocity is typically higher than average velocity (typically in the range of 0.66 to 0.80 depending on depth; USBR 2001) ~~to~~ due to friction from the channel bed and banks, VF_i is surface velocity from float in meters per second ($m s^{-1}$), d_i is depth (m), and w_i is width (m) of each sub-section (i = 1 to n, where n is the number of stations). A coefficient of 0.8 was used for all float method measurements in this study. Surface velocity for each sub-section was determined by measuring the amount of time it takes for a floating object to move a certain distance. For floats we used sticks found on site. Sticks are widely available (i.e. easiest for citizen scientists), generally float (except for the densest varieties of wood), and depending on their density, are between 40 and 80% submerged, which minimizes wind effects. An additional challenge with floats is that they can get stuck in eddies, pools, or overhanging vegetation.

Float method streamflow measurements involve the following steps:

1. Select stream reach with straight and uniform flow
2. Divide cross section into several sub-sections (n, typically between 5 and 20)
3. For each section, measure and record
    a. The depth in the middle of the sub-section
    b. The width of the sub-section
    c. The time it takes a floating object to move a known distance downstream (typically 1 or 2 m) in the middle of the sub-section
4. Solve for streamflow (Q) with Eq. (1)

1.3.2 Salt dilution method

There are two basic types of salt dilution flow measurements: slug (previously known as instantaneous) and continuous rate (Moore 2004a). Salt dilution measurements are based on the principle of the conservation of mass. In the case of the slug method, a single known volume of high concentration salt solution is introduced to a stream and the electrical conductivity (EC) is measured over time at a location sufficiently downstream to allow good mixing (Moore 2005). An approximation of the integral of EC as a function of time is combined with the volume of tracer and a calibration constant (Eq. 2) to determine discharge. In contrast, continuous rate salt dilution method involves introducing a known flow rate of salt solution into a stream (Moore 2004b). Slug method salt dilution measurements are broadly applicable in streams with flows up to 10 $m^3 s^{-1}$ with steep gradients and low background EC levels (Moore 2005). For the sake of citizen scientist repeatability, we chose to only investigate the slug method, because of the added complexity of measuring the flow rate of the salt solution for the continuous rate method. Some limitations of the salt dilution method include: (1) inadequate vertical and horizontal mixing of the tracer in the stream, (2) trapping of the tracer in slow moving pools of the stream, and (3) incomplete dilution of salt within the stream water prior to injection. The first two limitations can be addressed with proper site selection (i.e. well mixed reach with little slow-moving bank storage), while incomplete dilution can be avoided by proper training of the personnel performing the measurement.

Streamflow (Q; L s^{-1}) is solved for using Eq. (2) (Rantz 1982; Moore 2005):

$$Q = 1000 * \frac{V}{k\sum_{i=1}^{n}(EC(t) - EC_{BG})\Delta t} \quad (2)$$

where 1000 is a conversion factor from m^3 s^{-1} to L s^{-1}, V is the total volume of tracer introduced into the stream (m^3), k is the calibration constant in centimeters per microsiemens (cm μS^{-1}), n is the number of measurements taken during the breakthrough curve (unitless), EC(t) is the EC at time t (μS cm^{-1}), EC_{BG} is the background EC (μS cm^{-1}), and Δt is the change in time between EC measurements (s).

Salt dilution method streamflow measurements involve the following steps:

1. Select stream reach with turbulence to facilitate vertical and horizontal mixing
2. Determine upstream point for introducing the salt solution and a downstream point for measuring EC
    a. A rule of thumb in the literature is to separate these locations roughly 25 stream widths apart (Day 1977; Butterworth et al. 2000; Moore 2005)
3. Estimate flow either performing a "simplified float measurement (i.e. only a few sub-sections)" or by visually estimating width, average depth, and average velocity
4. Prepare salt solution based on the following guidelines (adapted from Moore 2005)
    a. 10000 ml of stream water for every 1 m^3 s^{-1} of estimated streamflow
    b. 1667 g of salt for every 1 m^3 s^{-1} of estimated streamflow
    c. Thoroughly mix salt and water until all salt is dissolved
    d. Following these guidelines ensure a homogenous salt solution with 1 to 6 salt to water ratio by mass
5. Establish the calibration curve relating EC values to actual salt concentrations (Moore 2004b) to determine calibration constant (k) relating changes in EC values in micro Siemens per centimeter (μS cm^{-1}) in the stream to relative concentration of introduced salt solution (RC) (See Sect. 2.1.3 for details)
6. Dump salt solution at upstream location
7. Measure EC at downstream location during salinity breakthrough until EC returns to EC_{BG}
    a. Recorded a video of the EC meter screen at the downstream location and later digitized the values using the time from the video and the EC values from the meter

8. Solve for streamflow (Q) with Eq. (2)

1.3.3 Bernoulli run-up method

Similar to the float method, Bernoulli run-up (or Bernoulli; USBR 2001) is based on the velocity-area principle. Total streamflow (Q; L s^{-1}) is calculated with Eq. (3):

$$Q = 1000 * \sum_{i=1}^{n} VB_i * d1_i * w_i \qquad (3)$$

where 1000 is a conversion factor from m^3 s^{-1} to L s^{-1}, VBi is velocity from Bernoulli run-up (m s^{-1}), $d1_i$ is depth (m), and w_i is width (m) of each sub-section (i = 1 to n). Area for each sub-section is the product of the width and the depth in the middle of each sub-section. Velocity for each sub-section (VB_i) was determined by measuring the "run-up" or change in water level on a thin meter stick (or "flat plate;" dimensions: 1 meter long, by 34 mm wide, by 1.5 mm thick used in this study) from when the flat plate was inserted parallel and then perpendicular to the direction of flow. The basic principle is that "run-up" on a flat plate inserted perpendicular to flow is proportional to velocity based on the solution to Bernoulli's equation. Velocity (VB_i; m s^{-1}) was calculated from Bernoulli's principle with Eq. (4):

$$VB_i = \sqrt{2g * (d2_i - d1_i)} \qquad (4)$$

where g is the gravitational constant (m s^{-2}) and $d2_i$ and $d1_i$ are the water depths (m) when the flat plate was perpendicular and parallel to the direction of flow, respectively.

Bernoulli method streamflow measurements involve the following steps:

1. Select constricted stream section with elevated velocity to increase the difference between d1i and d2i
2. Divide cross section into several sub-sections (n, typically between 5 and 20)
3. For each section, measure and record
    a. The depth with a flat plate held perpendicular to flow (d2i or the "Run-up" depth)
    b. The depth with a flat plate held parallel to flow (d1i or the actual water depth)
    c. The width of the sub-section
4. Solve for streamflow (Q) with Eq. (3) and Eq. (4)

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1.4 Research questions

Our ~~primary~~ aims in this paper were to (1) perform an initial ~~evaluate~~ evaluation of these three potential ~~citizen science~~simple streamflow measurement methods, (2) evaluate the same three methods with actual citizen scientists, and ~~select a preferred approach, and~~ (3) apply the selected method ~~pilot test the preferred approach~~ at a larger scale. Our research questions were:

- *Which simple streamflow measurement method provides the most accurate results when performed by "experts?"*
- *Which simple streamflow measurement method provides the most accurate results when performed by citizen scientists?*
- *What are citizen scientists' perceptions of the required training, cost, accuracy, etc. of the evaluated simple streamflow measurement methods?*
- *Can citizen scientists apply the selected streamflow measurement method at a larger scale?*

1.5 SmartPhones4Water

This research was performed in the context of a larger citizen science project called SmartPhones4Water or S4W (Davids et al. 2017; Davids et al. 2018; www.SmartPhones4Water.org). S4W focuses on leveraging citizen science, mobile technology, and young researchers to improve lives by strengthening our understanding and management of water. S4W's first pilot project, S4W-Nepal, initially concentrated on the Kathmandu Valley, and is now expanding into other regions of the country and beyond. All of S4W's efforts, including the research herein, have a focus on simple field data collection methods that can be standardized and scaled so that young researchers and citizen scientists can help fill data gaps in other data scarce regions. S4W-Nepal currently leverages the enthusiasm and schedule breaks in the academic calendar of ~~young researchers~~student citizen scientists to perform campaigns to improve our pre and post monsoon understanding of stone spouts (Nepali: dhunge dhara), land use, and now streamflow.

It should be noted that during the work documented by this paper, the use of "citizen scientist" is restricted to only student citizen scientists, which is a narrow (but important) range of potential citizen scientists. Our aim was to partner with student "citizen scientists" first to develop and evaluate streamflow measurement methodologies. Once methodologies are refined in coordination with students, it is our goal to partner with community members and students in the rural hills of Nepal to improve the availability of quantitative stream and spring flow data.

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2 Materials and methods

2.1 General

2.1.1 Types of streams evaluated

Streams evaluated during this investigation (Phases 1, 2, and 3) were a mixture of pool and drop and run stream types, with combinations of turbulent and laminar flow lines. Streamflows ranged from ~~1.4~~0.4 to 1804 L s^{-1}. Stream widths and average depths ranged from 0.1 to 6.0 m and 0.0040 and 0.97 m, respectively. Streambed materials ranged from cobles, gravels, and sands in the upper portions of watershed to sands, silts, and sometimes man-made concrete streambeds and side retaining walls in the lower portions. During pre-monsoon, sediment loads were generally low, while during post-monsoon, increased water velocities led to increased sediment loads (both suspended and bed). Slopes (based on Phase 2 data) ranged from 0.020 to 0.148 m m^{-1}. Additional details about the measurement sites are provided in Tables 3 and 4.

2.1.2 Reference flows

To evaluate different simple citizen science flow measurement methods, reference (or actual) flows for each site were needed. We used a SonTek FlowTracker acoustic Doppler velocimeter (ADV) to determine reference flows. The United States Geological Survey (USGS) mid-section method was used, following guidelines from USGS Water Supply Paper 2175 (Rantz 1982), along with instrument specific recommendations from SonTek's FlowTracker manual (SonTek 2009). Stream depths were shallow enough that a single vertical 0.6 depth velocity measurement (i.e. 40% up from the channel bottom) was used to measure average velocity for each sub-section. Depending on the total width of the channel, the number of sub-sections ranged from 8 to 30. The FlowTracker ADV has a stated velocity measurement accuracy of within one percent (SonTek 2009). Based on an ISO discharge uncertainty calculation within the SonTek FlowTracker software, the uncertainties in reference flows for Phase 1 and 2 ranged from 2.5 to 8.2 %, with a mean of 4.2 %. Based on the literature (Rantz 1982; Harmel 2006; Herschy 2014), these uncertainties in reference flows are towards the lower end of the expected range for field measurements of streamflow. Therefore, we do not think that any systematic biases or uncertainties in our data change the results of this paper. A compilation of the measurement reports generated by the FlowTracker ADV, including summaries of measurement uncertainty, are included as supplementary material.

2.1.3 Salt dilution calibration coefficient (k)

Our experience was that the most complicated portion of a salt dilution measurement was performing the dilution test to determine the calibration coefficient k. The calibration coefficient k relates changes in EC values in micro Siemens per centimeter (μS cm^{-1}) in the stream to relative concentrations of introduced salt solution (RC). During Phases 1 and 2, we determined k using a calibrated GHM 3431 [GHM-Greisinger] EC meter with the following steps (based on Moore 2004b):

1. Make diluted secondary solution by mixing 500 ml of stream water and 5 ml of salt solution

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2. Measure background stream water EC (EC_{BG})
3. Add known volume (typically 1 or 2 milliliters (ml)) of secondary solution to 500 ml of stream water in dilution cylinder
4. Measure new dilution cylinder EC
5. Repeat steps ~~5.c~~3 and ~~5.d~~4 until the full range of expected EC values ~~were~~are observed
6. Calculate RC for each measurement point
7. Plot EC on the horizontal axis and RC on the vertical axis
8. Perform linear regression
9. Obtain k from the slope of the linear regression

Due to the challenges of measuring k in the field, especially for citizen scientists who are the ultimate target for performing these streamflow measurements, average k values were used to determine salt dilution streamflows. For Phase 1, an average k of 2.79E-06 (n = 10) was used for all 20 measurement sites (Table 3). For Phase 2, an average k of 2.95E-06 (n = 15) was used for all 15 sites (Table 4). For Phase 3, the Phase 2 average k of 2.95E-06 was used to calculate~~d~~ streamflows for all salt dilution measurements. The impact of using average k values on salt dilution measurements is discussed in Sect. 4.1. Moore (2005) suggests that k is a function of (1) the ratio of salt and water in the tracer solution and (2) the chemical composition of the stream water. To minimize variability in k due to changes in salt concentration, a fixed ratio of salt to water (i.e. 1 to 6 by mass) was used to prepare tracer solutions for all phases of this investigation.

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2.1.4 Inexpensive EC meters

For Phases 2 and 3, ten inexpensive (i.e. $15) Water Quality Testers [HoneForest] were used to measure EC for salt dilution measurements. To evaluate the accuracy of these meters, we performed a six-point comparison test with reference EC values of 20.0, 107, 224, 542, 1003, and 1517 µS cm^{-1}, as determined by a calibrated GHM 3431 [GHM-Greisinger] EC meter. EC measurements were performed from low EC to high EC (for all six points) and were repeated three times for each meter. Because EC is used to compute the integral of the breakthrough curve (Eq. 2), the percent difference (errors) in EC changes between the six points (i.e. five intervals) from the inexpensive meters were compared to reference measurement differences (Fig. 1). Based on this analysis, the inexpensive meters had a positive median bias of roughly 5 % (ranging from -14 to 21 %) for EC value changes between 20 and 542 µS cm^{-1} (i.e. D1, D2, and D3). A nearly zero median bias (ranging from -5 to 5 %) for EC value changes between 542 and 1003 µS cm^{-1} (i.e. D4) was present. Finally, there was a negative median bias of roughly -9 % (ranging from -18 to 6 %) for EC value changes between 1003 and 1517 µS cm^{-1} (i.e. D5). No corrections were made to EC measurements collected with inexpensive [HoneForest] EC meters.

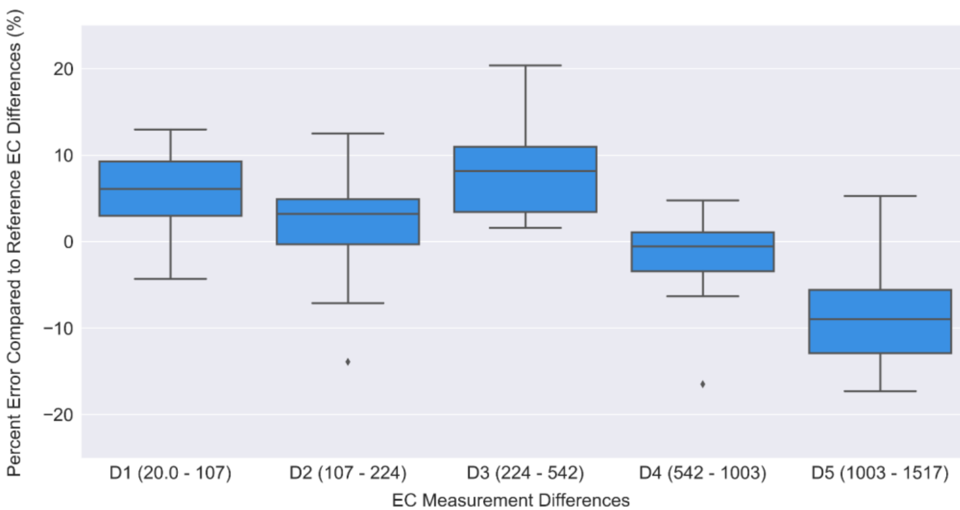

Figure 1: Box plots of the percent difference in EC measurements from inexpensive Water Quality Testers [HoneForest] for five different intervals (D1 to D5). The range of EC values from reference EC measurements (determined by a calibrated GHM 3431 [GHM-Greisinger] EC meter) shown in parentheses in µS cm^{-1}. Boxes show the inner-quartile range between the first and third quartiles of the dataset, while whiskers extend to show minimum and maximum values of the distribution, except for points that are determined to be "outliers" using a method that is a function of 1.5 times the inter-quartile range (Anon 2018).

2.2 Phases of the investigation

This investigation was carried out in three distinct phases including: Phase 1 - initial evaluation; Phase 2 - citizen scientist evaluation; and Phase 3 - citizen scientist application (Table 2).

Table 2. Brief descriptions of three data collection phases including who performed the field data collection, and what period and season the data were collected in.

#	Phase	Description	Performed by	Period	Season
1	Initial Evaluation	Initial evaluation of three simple flow measurement methods (i.e. float, salt dilution, and Bernoulli) along with FlowTracker ADV reference flow measurements at 20 sites within the Kathmandu Valley. Reference flows ranged from 6.4 to 240 L s^{-1}.	Authors	March/ April 2017	Pre-monsoon

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2	Citizen Scientist Evaluation	Citizen Scientist evaluation of three simple flow measurement methods (i.e. float, salt dilution, and Bernoulli) along "expert" and FlowTracker ADV reference flow measurements at 15 sites within the Kathmandu Valley. Reference flows ranged from 4.2 to 896 L s^{-1}.	Authors for "expert" and reference flows plus 10 Citizen Science Flow groups for simple methods	September 2018	Post-monsoon
3	Citizen Scientist Application	Salt dilution measurements at roughly 130 sites in the 10 perennial watersheds of the Kathmandu Valley. Float measurements with a small number of sub-sections (e.g. 3 to 5) performed at each site to determine salt dosage. Observed flows ranged between 0.4 to 425 and 1.~~5~~1 to 1804 L s^{-1} in pre and post-monsoon, respectively.	18 Citizen Science Flow groups (8 from April and 10 from September)	April and September 2018	Pre and Post Monsoon

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~~2.1~~2.2.1 ~~Citizen science streamflow measurement methods evaluated~~Initial evaluation (Phase 1)

~~The procedures for each of the three citizen science streamflow measurement methods evaluated are described in the following sections.~~

~~2.1.1 Float~~

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~~The float method is based on the velocity-area principle. Total streamflow (Q) in cubic meters per second (m^3 s^{-1}) was calculated with Eq. (1):~~

~~Eq. (1)~~ $\cancel{Q = \sum_{i=1}^{n} C * VF_i * d_i * w_i}$

~~where C is a unitless coefficient to account for the fact that surface velocity is typically higher than average velocity (typically in the range of 0.66 to 0.80 depending on depth; USBR 2001), VF_i is surface velocity from float in meters per second (m s^{-1}), d_i is depth (m), and w_i is width (m) of each sub-section (i = 1 to n, where n is the number of stations). Surface velocity for each sub-section was determined by measuring the amount of time it takes for a floating object to move a certain distance. For floats we used sticks found on site. Sticks are widely available (i.e. easiest for citizen scientists), generally float (except for the densest varieties of wood), and depending on their density are between 40 and 80% submerged, which minimizes wind effects.~~

~~Float measurements involved the following steps:~~

~~1. Selected stream reach with straight and uniform flow~~

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~~2. Divided cross section into several sub-sections (n, typically between 5 and 20)~~

~~3. For each section, measured and recorded~~

~~a. The depth in the middle of the sub-section~~

~~b. The width of the sub-section~~

~~c. The time it takes a floating object to move a known distance downstream (typically 1 or 2 m) in the middle of the sub-section~~

~~4. Solved for streamflow (Q) with Eq. (1)~~

~~**2.1.2** Salt dilution~~

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~~There are two basic types of salt dilution flow measurements: slug (previously known as instantaneous) and continuous rate (Moore 2004a). Salt dilution measurements are based on the principle of the conservation of mass. In the case of the slug method, a single known volume of high concentration salt solution is introduced to a stream and the electrical conductivity (EC) is measured over time at a location sufficiently downstream to allow good mixing (Moore 2005). In contrast, continuous rate salt dilution method involves introducing a known flow rate of salt solution into a stream (Moore 2004b). Slug method salt dilution measurements are broadly applicable in streams with flows up to 10~~ ~~$m^3 s^{-1}$~~ ~~with steep gradients and low background EC levels (Moore 2005). For the sake of citizen scientist repeatability, we chose to only investigate the slug method, because of the added complexity of measuring the flow rate of the salt solution for the continuous rate method.~~

~~Streamflow (Q;~~ ~~$m^3 s^{-1}$~~~~) was solved for using Eq. (2) (Rantz 1982; Moore 2005):~~

~~Eq. (2)~~ $$\cancel{Q = \frac{V}{k\sum_{i=1}^{n}(EC(t) - EC_{BG})\Delta t}}$$

~~where V is the total volume of tracer introduced into the stream (~~~~m^3~~~~), k is the calibration constant in centimeters per microsiemens (~~~~$cm\ \mu S^{-1}$~~~~), n is the number of measurements taken during the breakthrough curve (unitless), EC(t) is the EC at time t (~~~~$\mu S\ cm^{-1}$~~~~),~~ ~~EC_{BG}~~ ~~is the background EC (~~~~$\mu S\ cm^{-1}$~~~~), and Δt is the change in time between EC measurements (s).~~

~~We performed the following steps when making a salt dilution measurement:~~

~~1. Selected stream reach with turbulence to facilitate vertical and horizontal mixing~~

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~~2. Determined upstream point for introducing the salt solution and a downstream point for measuring EC~~

~~a. A rule of thumb in the literature is to separate these locations roughly 25 stream widths apart (Day 1977; Butterworth et al. 2000; Moore 2005)~~

~~3. Estimated flow rate visually by estimated width, average depth, and average velocity~~

~~4. Prepared salt solution based on the following guidelines (adapted from Moore 2005)~~

a. 10000 ml of stream water for every 1 $m^3 s^{-1}$ of estimated streamflow

b. 1667 g of salt for every 1 $m^3 s^{-1}$ of estimated streamflow

c. Thoroughly mix salt and water until all salt is dissolved

d. Following these guidelines ensured a homogenous salt solution with 1 to 6 salt to water ratio by mass

5. Performed dilution test (Moore 2004b) to determine calibration constant (k) relating changes in EC values in micro Siemens per centimeter (µS cm^{-1}) in the stream to relative concentration of introduced salt solution (RC)

a. Made diluted secondary solution by mixing 500 ml of stream water and 5 ml of salt solution

b. Measured background stream water EC (EC_{BG})

c. Added known volume (typically 1 or 2 milliliters (ml)) of secondary solution to 500 ml of stream water in dilution cylinder

d. Measured new dilution cylinder EC

e. Repeated steps 5.c and 5.d until the full range of expected EC values were observed

f. Calculated RC for each measurement point

g. Plotted EC on the horizontal axis and RC on the vertical axis

h. Performed linear regression

i. Obtained k from the slope of the linear regression

6. Dumped salt solution at upstream location

7. Measured EC at downstream location during salinity breakthrough until EC returns to EC_{BG}

a. Recorded a video of the EC meter screen at the downstream location and later digitized the values using the time from the video and the EC values from the meter

8. Solved for streamflow (Q) with Eq. (2)

2.1.3 Bernoulli run-up

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Similar to the float method, Bernoulli run-up (or Bernoulli) is based on the velocity-area principle. Total streamflow (Q; $m^3 s^{-1}$) was calculated with Eq. (3):

Eq. (3) $$Q = \sum_{i=1}^{n} VB_i * d1_i * w_i$$

where VB_i is velocity from Bernoulli run-up (m s^{-1}), $d1_i$ is depth (m), and w_i is width (m) of each sub-section (i = 1 to n). Area for each sub-section is the product of the width and the depth in the middle of each sub-section. Velocity for each sub-section (VB_i) was determined by measuring the "run-up" or change in water level on a thin meter stick from when the stick was inserted parallel and then perpendicular to the direction of flow. The basic principle is that "run-up" on a flat plate inserted perpendicular to flow is proportional to velocity based on the solution to Bernoulli's equation. Velocity (VB_i; m s^{-1}) was calculated from Bernoulli's principle with Eq. (4):

~~Eq. (4)~~ $\cancel{VB_i = \sqrt{2g*(d2_i - d1_i)}}$

~~where g is the gravitational constant (m s^-2^) and d2_i and d1_i are the water depths (m) when the flat plate was perpendicular and parallel to the direction of flow, respectively.~~

~~Bernoulli run-up measurements involved the following steps:~~

~~1. Selected constricted stream with elevated velocity to increase the difference between d1i and d2i~~

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~~2. Divided cross section into several sub-sections (n, typically between 5 and 20)~~

~~3. For each section, measured and recorded~~

~~a. The depth with a flat plate held perpendicular to flow (d2i or the "Run-up" depth)~~

~~b. The depth with a flat plate held parallel to flow (d1i or the actual water depth)~~

~~c. The width of the sub-section~~

~~4. Solved for streamflow (Q) with Eq. (3) and Eq. (4)~~

~~2.2 Reference flow~~

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~~To evaluate the different citizen science flow measurement methods, a reference (or actual) flow for each site was needed. We used a SonTek FlowTracker acoustic Doppler velocimeter (ADV) to determine reference flows. The United States Geological Survey (USGS) mid-section method was used, following guidelines from USGS Water Supply Paper 2175 (Rantz 1982), along with instrument specific recommendations from SonTek's FlowTracker manual (SonTek 2009). The FlowTracker ADV has a stated velocity measurement accuracy of within one percent (SonTek 2009). Flow measurement errors, calculated with an International Standards Organization (ISO) approach built into the FlowTracker software, are typically in the range of 3 to 10 %. Reference flow errors in this study are discuss in Section 4.5. A compilation of the measurement reports generated by the FlowTracker ADV are included as supplementary material.~~

~~2.3 Flow measurement method evaluation and analysis~~

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To perform an initial evaluation of the selected methods, we (the authors) performed measurements at 20 sites in March and April of 2017 in headwater catchments of the Kathmandu Valley (Fig. 2). Sites were chosen to represent a typical range of stream types, slopes, and flow rates. At each site, we performed float, salt dilution, and Bernoulli measurements, in addition to reference flow measurements with the FlowTracker ADV per the descriptions in Sect. 1.3 and 2.1.2, respectively. All Phase 1 salt dilution EC measurements were taken with a calibrated GHM 3431 [GHM-Greisinger] EC meter.

At each site, measurements were performed consecutively, and took roughly one to two hours to perform, depending on the size of the stream and the resulting number of sub-sections for float, Bernoulli, and reference flow measurements.

Measurements were performed during steady state conditions in the stream; if runoff generating precipitation occurred during measurements at a site, the measurements were stopped, and repeated after streamflows stabilized at pre-event levels. As previously described, salt dilution calibration coefficient k was determined at 10 of the 20 sites. Field notes for float, salt dilution, and Bernoulli were taken manually and later digitized into a spreadsheet (included in supplementary materials). Results from Phase 1 are summarized in map and tabular form (Fig. 2; Table 3).~~We first summarized flow measurement method evaluation results in map and tabular form (Fig. 1; Table 1). Measurement ID can be used to link data between the map and table. We used scatter plots to compare reference flow (x-axis) to the three flow measurement methods evaluated (y-axis) to visualize and interpret results from each method. We fitted these points with a linear regression forced through the origin.~~ To understand relative (normalized) errors, we calculated percent differences in relation to reference flow for each method. Averages of absolute value percent differences (absolute errors), average errors (bias), and standard deviations of errors were used as metrics to compare results among methods and between Phase 1 and 2.~~To better understand possible explanations for observed variability in our results, we performed a correlation analysis. For each method, we performed a Pearson's r correlation analysis (Lee Rodgers and Nicewander 1988) between the absolute value of percent difference in flow and (1) reference flow, (2) average velocity, (3) EC_{BG}, and (4) slope. Slope values were developed using elevations from the Google Earth Digital Elevation Model (DEM) obtained along the centreline of the stream alignment both 100 meters upstream and downstream of each measurement point (retrieved July 2nd, 2018). While using DEM data for slope calculations is clearly inferior to performing topographic surveys in the field, this was not possible due to lack of equipment and time; therefore, these slope data are the best available numbers.~~

~~2.4 Salt dilution calibration coefficient (k) analysis~~

~~Arguably, one of the most complicated portions of a salt dilution measurement is performing the dilution test to determine the calibration coefficient k (Moore 2004b). To determine if the dilution test needs to be repeated for each citizen science measurement, we analyzed all k values determined during this study. In addition to the mean, range, and standard deviation, we performed a Pearson's r correlation analysis (Lee Rodgers and Nicewander 1988) to see if k showed statistically significant trends with latitude, longitude, elevation, and EC_{BG}.~~

2.2.2 Citizen scientist evaluation (Phase 2)

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To evaluate the same three streamflow measurement methods with actual citizen scientists, we recruited 37 student volunteers from Khwopa College of Engineering in Bhaktapur, Nepal for our Citizen Science Flow (CS Flow) evaluation. 10 CS Flow evaluation groups of either three or four members were formed. Citizen scientists were ~~all~~second and third-year civil engineering Bachelors' students ranging in age from 21 to 25; 1~~3~~2 were female and 2~~4~~5 were male. Phase 2 started on 17 September (2018) with a four-hour theoretical training on the float, salt dilution, and Bernoulli streamflow measurement methods per Sect. 1.3. The theoretical training also introduced citizen scientists to Open Data Kit (ODK; Anokwa et al. 2009) in general, and the specific streamflow measurement workflow described below.

Based on ~~the~~our initial experiences and results from ~~this~~Phase 1~~ study, S4W-Nepal~~we developed an ~~Open Data Kit (ODK; Anokwa et al. 2009)~~ ODK form to facilitate the collection of float, salt dilution, Bernoulli, and reference streamflow measurement data.~~for citizen scientists to perform salt dilution measurements.~~ After installing ODK on an Android smartphone, and downloading the necessary form from S4W-Nepal's ODK Aggregate server on the Google Cloud App Engine, ~~T~~the general workflow was as follows:

1. Launch ODK and select Stream Flow (v1.1) form
2. Record measurement date and time and GPS coordinates
3. Select flow measurement methods to perform (i.e. float, salt dilution, and Bernoulli)
    a. Note that the "expert" group also selected FlowTracker for reference flow
4. Record float data (e.g. distance, time, depth, width) per Sect. 1.3.1
5. Record Bernoulli data (e.g. depth1, depth2, width) per Sect. 1.3.3
6. Use float flow measurement results to determine recommended salt dose per Sect. 1.3.2
7. Record GPS and take pictures of ~~the~~ salt injection ~~and EC measurement~~ locations
8. Enter actual amount of salt used based on possible combinations of pre-weight packets of salt (e.g. 10 g, 20 g, 50 g, 100 g, 500 g, etc.)
9. Based on actual amount of salt used, the app calculates the amount of stream water needed to prepare the tracer solution
10. Prepare tracer solution using pre-weighed salt packets and graduated measuring cylinders
11. ~~Take pictures and r~~Record GPS and take pictures of ~~salt injection and~~ EC measurement locations
12. Add tracer solution to stream and record~~ed~~ video of EC breakthrough curve
    a. Note that all Phase 2 salt dilution EC breakthrough curve measurements were performed with inexpensive [HoneForest] meters.
13. Submit form to ODK Aggregate server

Training was continued on 18 September with a two-hour field demonstration session in the Dhobi watershed located in the north of the Kathmandu Valley (Fig. 3). During this field training, we worked with three to four groups at a time, and together performed float, salt dilution, and Bernoulli measurements at site D3.

Following the field training, a Google My Map with 15 measurement sites was provided to the citizen scientists: seven in the Dhobi and eight in the Nakkhu watersheds (Fig. 3). Sites were chosen to represent a typical range of stream types, slopes, and flow rates found within the headwater catchments of the Kathmandu Valley, and to minimize travel time between locations. Groups were strictly instructed to not discuss details regarding the selection of measurement reaches or the results of the streamflow measurements with other groups. For the remainder of 18 September and all of 19 September, the 10 CS Flow groups rotated between the seven sites in the Dhobi watershed. To ensure that measurements could be compared with each other, four S4W-Nepal interns travelled between sites to verify that CS Flow groups performed measurements on the same streams in the same general locations. All eight measurements on the Nakkhu watershed were performed in similar fashion on 20 September.

Using the same schedule of the CS Flow groups, the “expert” group (authors) visited the same 15 sites. At each site, in addition to performing float, salt dilution, and Bernoulli measurements, the “expert” group performed (1) reference flow measurements per Sect. 2.1.2, (2) salt dilution calibration coefficient k dilution measurements per Sect. 2.1.3, and (3) an auto-level survey to determine average stream slope. At each site, auto-level surveys included topographical surveys of stream water surface elevations with a AT-B4 24X Auto-Level [Topcon] at five locations including: 10 times and 5 times the stream width upstream of the reference flow measurement site (reference site), at the reference site, and 5 and 10 times the stream width downstream of the reference site. For each site, stream slope was taken as the average of the four slopes computed from the five water surface elevations measured.

All CS Flow and “expert” measurements were conducted under steady state conditions. Based on two S4W-Nepal citizen scientists’ precipitation measurements (official government records aren’t available until the subsequent year) nearby the Dhobi sites (i.e. roughly 3 km to the west and east), no measurable precipitation occurred during 18 and 19 September. Water level measurements from a staff gauge installed at site D3 taken at the beginning and end of 18 and 19 September confirmed that water levels (and therefore flows) remained steady. On 20 September, 7 mm of precipitation was recorded by a~~n~~ S4W-Nepal citizen scientist in Tikabhairab which is roughly 1 km north of the eight measurement sites in the Nakkhu watershed. Based on field observations of the “expert” group, rain didn’t start until 15:30 LT, and all CS Flow group measurements were completed before 15:30 LT. Three “expert” measurement sites were completed after 15:30 LT, but most rain was concentrated downstream (to the north) of these sites (i.e. N1, N2, and N3). Based on water level measurements performed at the beginning, middle, and end of measurements at these sites, no changes in water levels (and therefore flows) were observed. We also don’t see any systematic impacts to the resulting comparison data for these sites (Table 4 and Fig. 4).

Once ODK forms from all 15 sites were finalized and submitted to the ODK Aggregate server, CS Flow and “expert” groups digitized breakthrough curves (i.e. time and EC) from EC videos in shared Google Sheet salt dilution flow calculators. Digitizations for all measurements were then reviewed for accuracy and completeness by the authors.

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~~(1) selected an appropriate measurement reach with good mixing and minimal bank storage, (2) performed a simplified float measurement (i.e. only a 3 or 4 depths and velocities), (3) used the float flow estimate and ECBG to provide citizen scientists recommended salt/water dose, (4) used pre-weight packets of salt (e.g. 10 g, 20 g, 50 g, 100 g, etc.) to prepare tracer solution, (5) added tracer solution to stream and recorded video of EC breakthrough curve, (6) submitted form to ODK Aggregate server, (6) digitized breakthrough curve (i.e. time and EC) in shared Google Sheet salt dilution flow calculator.~~
After the completion of Phase 2 field work, a Google Form survey was completed by 33 of the Phase 2 citizen scientists. The purpose of the survey was to evaluate citizen scientists' perceptions of the three simple streamflow measurement methods. The survey questions forced participants to rank each method from 1 to 3. Questions were worded so that in all cases, a rank of 1 was most favourable and 3 was least favourable. The following survey questions were included:

- Q1 - Required training for each method (1 least and 3 most)
- Q2 - Cost of equipment for each method (1 least and 3 most)
- Q3 - Number of citizen scientists required for each method (1 least and 3 most)
- Q4 - Data recording requirements for each method (1 least and 3 most)
- Q5 - Complexity of procedure for each method (1 least and 3 most)
- Q6 - Enjoyability of measurement method (1 most enjoyable and 3 least enjoyable)
- Q7 - Safety of each method (1 safest and 3 least safe)
- Q8 - Accuracy of each method (1 most accurate and 3 least accurate)

A tabular summary of the 15 Phase 2 measurement locations was developed (Table 4). To understand relative (normalized) errors, we calculated percent differences in relation to reference flow for each method. Averages of absolute value percent differences (absolute errors), average errors (bias), and standard deviations of errors were used as metrics to compare results among methods and between Phase 1 and 2. Box plots showing the distribution of CS Flow group measurement errors along with "expert" measurement errors for each method were developed (Fig. 4). To visualize the results of the citizen scientists' perception survey, a stacked horizontal bar plot grouped by streamflow measurement methods was developed (Fig. 5).

~~2.5~~2.2.3 ~~2.5.~~ Citizen scientist application~~CS Flow campaign - pilot testing of salt dilution method~~ (Phase 3)

From 15 to 21 of April (2018; pre-monsoon) and 21 to 25 of September (2018; post-monsoon), 25 and 37 second and third-year engineering Bachelors' student citizen scientists, respectively, from Khwopa College of Engineering in Bhaktapur, Nepal joined S4W-Nepal's Citizen Science Flow (CS Flow) campaign. Citizen scientists formed~~Based on the initial results from this study, S4W-Nepal developed an Open Data Kit (ODK; Anokwa et al. 2009) form for citizen scientists to perform salt dilution measurements. The general workflow was (1) selected an appropriate measurement reach with good mixing and minimal bank storage, (2) performed a simplified float measurement (i.e. only a 3 or 4 depths and velocities), (3) used the~~

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~~float flow estimate and EC_{BG} to provide citizen scientists recommended salt/water dose, (4) used pre-weight packets of salt (e.g. 10 g, 20 g, 50 g, 100 g, etc.) to prepare tracer solution, (5) added tracer solution to stream and recorded video of EC breakthrough curve, (6) submitted form to ODK Aggregate server, (6) digitized breakthrough curve (i.e. time and EC) in shared Google Sheet salt dilution flow calculator.~~

~~During S4W-Nepal's Citizen Science Flow (CS Flow) campaign (15th to 21st of April 2018; Fig. 6), student volunteers from Khwopa College of Engineering~~ 8 pre-monsoon and 10 post-monsoon CS Flow groups of three or four people each, respectively. Ages of pre-monsoon citizen scientists ranged from 21 to 25; 7 were female and 18 were male (post-monsoon group composition is described in Sect. 2.2.2). ~~were recruited, trained, divided into groups by sub-watershed, and sent to the field to perform salt dilution flow measurements.~~

Post-monsoon Phase 3 measurements were performed by the same 10 CS Flow groups that performed Phase 2 citizen scientist evaluations. Therefore, additional training for these groups was not necessary. Training for pre-monsoon CS Flow groups included a four-hour theoretical training on 15 April about the float and salt dilution streamflow measurement methods per Sect. 1.3. The theoretical training also introduced citizen scientists to ODK Android data collection application. For both pre and post-monsoon Phase 3 measurements, the workflow was similar to that described in Sect. 2.2.2, with the exceptions of (1) skipping step 5 (the collection of Bernoulli data), and (2) only performing a "simplified" float measurement (step 4) involving only two or three sub-sections in order to have a flow estimate for calculating the recommended salt dose (step 6). Training was continued on the afternoon of 15 April with a two-hour field demonstration session in the Hanumante watershed located in the southwestern portion of the Kathmandu Valley (Fig. 6). During this field training, we worked with four groups at a time, and together performed "simplified" float and Bernoulli measurements at two sites.

After training was completed, citizen scientists were sent to the field to perform streamflow measurements as described above in all 10 headwater catchments of the Kathmandu Valley (Fig. 6). Note that all Phase 3 salt dilution EC breakthrough curve measurements were performed with inexpensive [HoneForest] meters. Once ODK forms from all Phase 3 measurements were finalized and submitted to the ODK Aggregate server, CS Flow groups digitized breakthrough curves (i.e. time and EC) from EC videos in shared Google Sheet salt dilution flow calculators. Digitizations for all measurements were then reviewed for accuracy and completeness by the authors. ~~In the second week, student volunteers used a salt dilution Google Sheet flow calculator to digitize collected measurement data and compute flow (see supplementary material for Excel version).~~ While not included in this paper, it is important to note that ~~Students~~ students analyzed the collected flow data (third week) and finally presented oral and written summaries of their quality-controlled results to their faculty and peers ~~and~~at Khwopa College of Engineering. ~~S4W-Nepal currently leverages the enthusiasm and schedule breaks in the academic calendar of young researchers to perform campaigns to improve our pre and post monsoon understanding of stone spouts (Nepali: dhunge dhara), land use, and now streamflow.~~

~~To analyze the generated streamflow data, we developed a scatter plot between flow estimates from the simplified float method (used to calculated salt dosage) and the salt dilution flow results. At locations were S4W-Nepal takes regular FlowTracker measurements, we compared the most recent S4W-Nepal observation(s) to CS Flow salt dilution measurements. Because salt dilution measurements were performed during the pre-monsoon period when precipitation is minimal, hydrographs are relatively steady with gradual recession over time as the South Asian Monsoon approaches. Therefore, we did not expect differences in time (e.g. plus or minus one month roughly) between the two measurements to greatly impact the resulting comparisons.~~While subsequent work will highlight the knowledge about spring and streamflows gained from these data, the purpose herein is more a proof of concept showing that the salt dilution method can be successfully applied at a larger scale. As such, a simple map figure is used to show the spatial distribution of pre and post-monsoon measurements. The three streamflow gauging stations within the Kathmandu Valley (only one in a headwater catchment) operated by the ~~, indicating that the~~ official government agency responsible for streamflow measurements (i.e. the Department of Hydrology and Meteorology or DHM) ~~operates three gauging stations within the Kathmandu Valley~~are also included. Additionally, ~~H~~histograms of flow and EC for pre and post-monsoon are also shown. While measurements in pre and post-monsoon were not all taken in the same locations, histograms can still be used to see seasonal changes in distributions.

3 Results

~~3~~ The following results section is organized into the same three primary sub-sections included in the methodology (Sect. 2.2): initial evaluation (Phase 1), citizen scientist evaluation (Phase 2), and citizen scientist flow application (Phase 3).

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3.1 Initial evaluation results (Phase 1)

~~3.1~~ For Phase 1 evaluation of the three simple streamflow measurement methods, ~~Summary of evaluation measurements~~

~~W~~we performed sets of ~~evaluation~~ measurements at 20 sites within the Kathmandu Valley, Nepal (Fig. ~~1~~2.a and 2.b). The Kathmandu Valley is a small intermontane basin roughly 25 km in diameter with a total area of 587 km2 in the Central Region of Nepal, and encompasses most of Kathmandu, Bhaktapur, and Lalitpur districts. Elevations of measurements ~~at elevations~~ rang~~ing~~ed from 1313 to 1905 meters above mean sea level. Salt dilution calibration coefficients (k) averaged 2.79E-06 and ranged from 2.57E-06 to 3.02E-06. Reference ~~Flows~~ flows evaluated ranged from ~~0.006~~6.4 to ~~0.24~~240~~0~~ ~~m^3~~ L s^{-1} (Table ~~1~~3; sorted in ascending order by reference flow). Absolute errors~~Percent differences~~ with respect to reference flows averaged ~~7.9~~23, ~~8.2~~15, and ~~25.7~~37 %, while ~~and standard deviations (std dev) of 29.1, 17.2, and 61.9 % were~~

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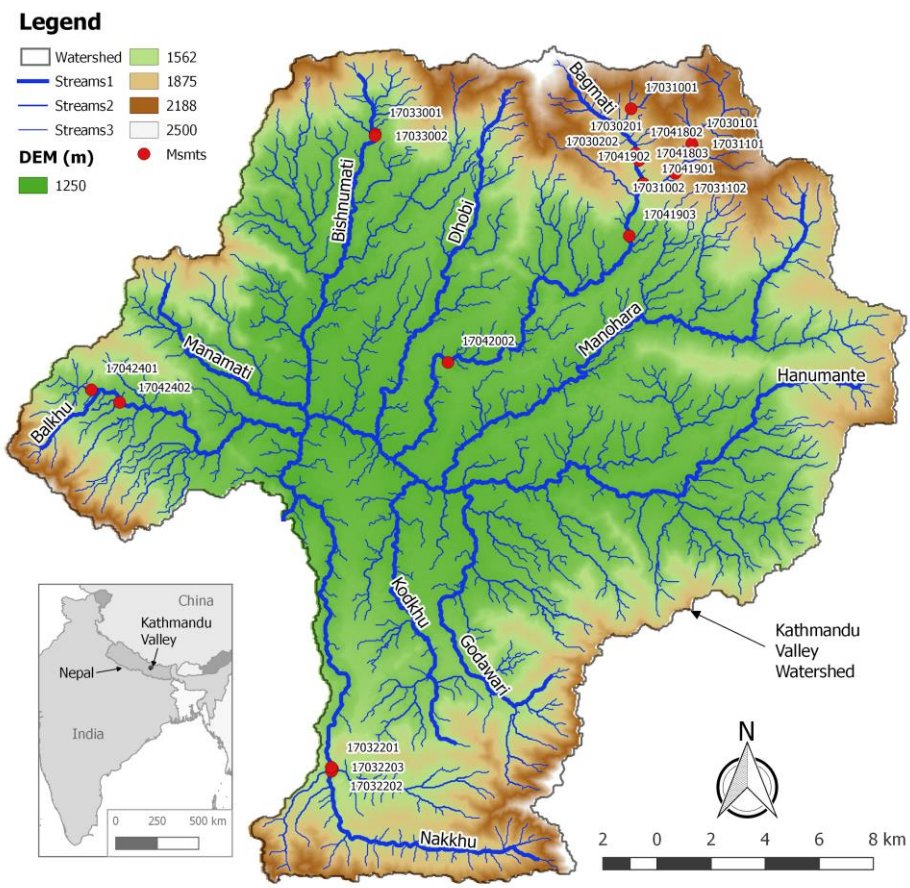
~~observed for float, salt dilution, and Bernoulli methods, respectively (Table 1).~~ biases for all methods were positive, averaging 8, 6, and 26 % for float, salt dilution, and Bernoulli methods, respectively (Table 3). Standard deviations of errors were 29, 19, and 62 % for float, salt dilution, and Bernoulli methods, respectively. The largest salt dilution errors occurred for reference flows of 21 L s^{-1} or less (i.e. sites 1 through 7), while float and Bernoulli errors were more evenly distributed through the range of observed flows.

Figure 2.c is a photograph of the typical types of relatively steep pool and drop stream systems included in Phase 1. Field notes from Bernoulli flow measurements for two measurements (~~Msmt~~ Site IDs ~~17041903-~~9 and ~~17031102~~19) were destroyed by water damage, so Bernoulli flow and percent difference data were not available for these sites. Detailed reports for reference flow measurements along with calculations for each simplified streamflow measurement method are included as ~~Plots of EC and change in EC as a function of time for all 20 salt dilution measurements are shown in Fig. 2. Additional data for evaluation measurements is included as~~ supplementary material.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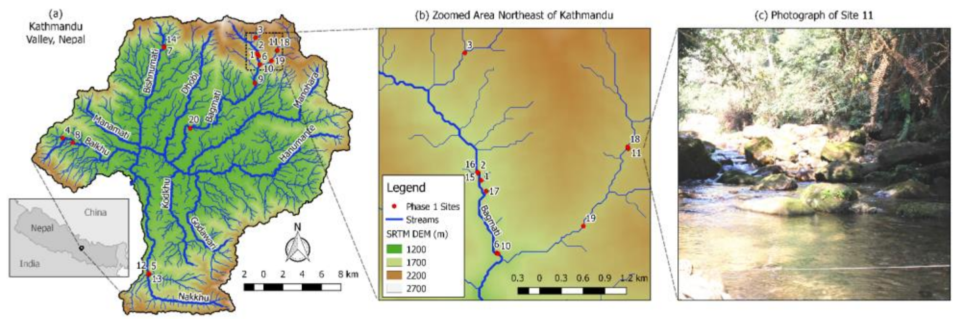

Figure 22~~1~~: Map ~~figure~~ showing ~~the~~ topography (green to tan to white color gradation) of the Kathmandu Valley from a Shuttle Research Telemetry Mission (SRTM 2000) Digital Elevation Model (DEM), resulting stream network (Davids et al. 2018), and locations of ~~flow~~ phase 1 measurement sites (a)~~measurements (msmts)~~. Names of the ten historically perennial tributaries are shown. Panel (b) shows an enlarged view of the area where 11 of the 20 measurements were taken. Panel (c) is a photograph of site 11, a pool and riffle sequence flowing at roughly 100 L s^{-1}. Measurement ~~points~~ sites are labelled with Phase 1 ~~measurement~~ Site IDs ~~(msmt_id)~~. ~~Names of the ten historically perennial tributaries are shown.~~

Table 3: Summary of initial evaluation (Phase 1) measurement comparison data. Records sorted in ascending order by reference flow (Q Reference). Latitude and longitude in reference to the WGS84 datum. All flow values shown are shown in L s^{-1} rounded to the nearest integer for values greater than or equal to 10 and to the nearest tenth place for values less than 10. Percent differences (errors) calculated using Q Reference (FlowTracker) as the actual flow. Data summarized at the bottom with average, minimum (min), maximum (max), and standard deviation (std dev). Note that averages (avg *) shown in the summary area near the bottom for the last three columns (i.e. percent errors) include averages of absolute values of percent errors (i.e. absolute errors) shown underlined in parentheses. Null (empty) cells indicate that data for that site and parameter were either damaged or not collected in the field. Average k (2.79E-06) was used to compute Q salt for all Phase 1 sites.

Site ID	Date	Latitude	Longitude	Elev-ation (m)	K (cm µS^{-1})	Q Ref-erence (L s^{-1})	Q Float (L s^{-1})	Q Salt (L s^{-1})	Q Ber-noulli (L s^{-1})	% Error, Float	% Error, Salt	% Error, Ber-noulli
1	02/03/17	27.78065	85.42426	1649		6.4	7.4	4.3	8.8	16	-34	37
2	18/04/17	27.78158	85.42385	1659		6.9	8.0	7.5	10	15	9	45
3	10/03/17	27.79649	85.42177	1905	2.76E-06	11	7.8	12	8.8	-28	10	-19
4	24/04/17	27.70026	85.22077	1406		17	19	19	18	11	13	5
5	22/03/17	27.57487	85.31314	1482	2.80E-06	18	20	24	19	12	38	5
6	19/04/17	27.77164	85.42657	1609		19	28	28	22	48	49	16
7	30/03/17	27.78691	85.32589	1364	2.57E-06	21	26	27	48	27	32	132
8	24/04/17	27.69620	85.23142	1382		23	9.5	25	6.3	-59	7	-73
9	19/04/17	27.75406	85.42170	1355		34	51	34		52	0	
10	19/04/17	27.77154	85.42680	1609		41	41	48	63	0	16	53
11	01/03/17	27.78483	85.44480	1877		104	111	85	101	7	-18	-3
12	22/03/17	27.57542	85.31268	1477	2.67E-06	111	106	115	116	-4	4	5
13	22/03/17	27.57410	85.31277	1481	2.83E-06	117	81	128	102	-31	10	-13

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14	30/03/17	27.78627	85.32583	1356	2.74E-06	153	208	141	470	37	-7	208
15	02/03/17	27.78156	85.42383	1659		155	248	130	161	59	-16	4
16	18/04/17	27.78168	85.42373	1663		156	140	144	210	-10	-8	34
17	10/03/17	27.77932	85.42496	1653	2.80E-06	159	183	155	228	15	-2	43
18	11/03/17	27.78505	85.44473	1877	2.91E-06	208	221	216	150	7	4	-28
19	11/03/17	27.77514	85.43867	1806	3.02E-06	230	188	237		-18	3	
20	20/04/17	27.71106	85.35432	1313	2.78E-06	240	246	267	264	3	12	10
			avg * ->	1579	2.79E-06	92	97	92	111	8 (23)	6 (15)	26 (37)
			min ->	1313	2.57E-06	6.4	7.4	4.3	6.3	-59	-34	-73
			max ->	1905	3.02E-06	240	248	267	470	59	49	208
			std dev ->	190	1.22E-07	81	89	82	122	29	19	62

~~Table 1: Tabular summary of measurement comparison data. Records sorted in ascending order by reference flow (Q Reference). Latitude and longitude in reference to the WGS84 datum. All flow values shown are shown in m^3 s^{-1} rounded to the thousandth place. Percent differences calculated using Q Reference (FlowTracker) as the actual flow. Data summarized at the bottom with average, minimum (min), maximum (max), and standard deviation (std dev). Note that measurement ID (Msmt ID) is comprised of two digits for year, month, date, and measurement number starting at 01 each day.~~

Msmt ID	Latitude	Longitude	Elev-ation (m)	Q Reference (m3 s-1)	Q Float (m3 s-1)	Q Salt (m3 s-1)	Q Bernoulli (m3 s-1)	% Diff-erence Float	% Diff-erence Salt	% Diff-erence Bernoulli
17030202	27.78065	85.42426	1649	0.006	0.007	0.006	0.009	15.6	-12.5	37.5
17041802	27.78158	85.42385	1659	0.007	0.008	0.007	0.010	15.9	7.2	44.9
17031001	27.79649	85.42177	1905	0.011	0.008	0.012	0.009	-28.4	11	-19.3
17042401	27.70026	85.22077	1406	0.017	0.019	0.019	0.018	11.2	11.2	4.7
17032201	27.57487	85.31314	1482	0.018	0.020	0.024	0.019	12.4	37.3	5.1
17041901	27.77164	85.42657	1609	0.019	0.028	0.027	0.022	48.4	47.3	16.7
17033001	27.78691	85.32589	1364	0.021	0.026	0.030	0.048	27.2	43.2	132
17042402	27.69620	85.23142	1382	0.023	0.010	0.025	0.006	-59.2	5.2	-73
17041903	27.75406	85.42170	1355	0.034	0.051	0.033		51.6	-0.9	
17041902	27.77154	85.42680	1609	0.041	0.041	0.047	0.063	0.5	14.6	53.2
17030101	27.78483	85.44480	1877	0.104	0.111	0.088	0.102	6.9	-15.9	-2.6
17032203	27.57542	85.31268	1477	0.111	0.106	0.120	0.116	-4.3	8	5.1
17032202	27.57410	85.31277	1481	0.117	0.081	0.126	0.102	-30.7	8	-13.2
17033002	27.78627	85.32583	1356	0.153	0.208	0.144	0.470	36.5	-5.6	207.9
17030201	27.78156	85.42383	1659	0.155	0.248	0.176	0.161	59.3	13.1	3.5
17041803	27.78168	85.42373	1663	0.156	0.140	0.142	0.210	-10.4	-8.9	34.4
17031002	27.77932	85.42496	1653	0.159	0.183	0.155	0.228	15.2	-2.8	43.4
17031101	27.78505	85.44473	1877	0.208	0.221	0.207	0.150	6.5	-0.6	-27.8
17031102	27.77514	85.43867	1806	0.230	0.188	0.219		-18	-4.8	
17042002	27.71106	85.35432	1313	0.240	0.246	0.264	0.264	2.7	10.2	10.1
		Average ->	1579	0.092	0.098	0.094	0.112	7.9	8.2	25.7
		min ->	1313	0.006	0.007	0.006	0.006	-59.2	-15.9	-73.0
		max ->	1905	0.240	0.248	0.264	0.470	59.3	47.3	207.9
		std dev ->	190	0.081	0.089	0.081	0.122	29.1	17.2	61.9

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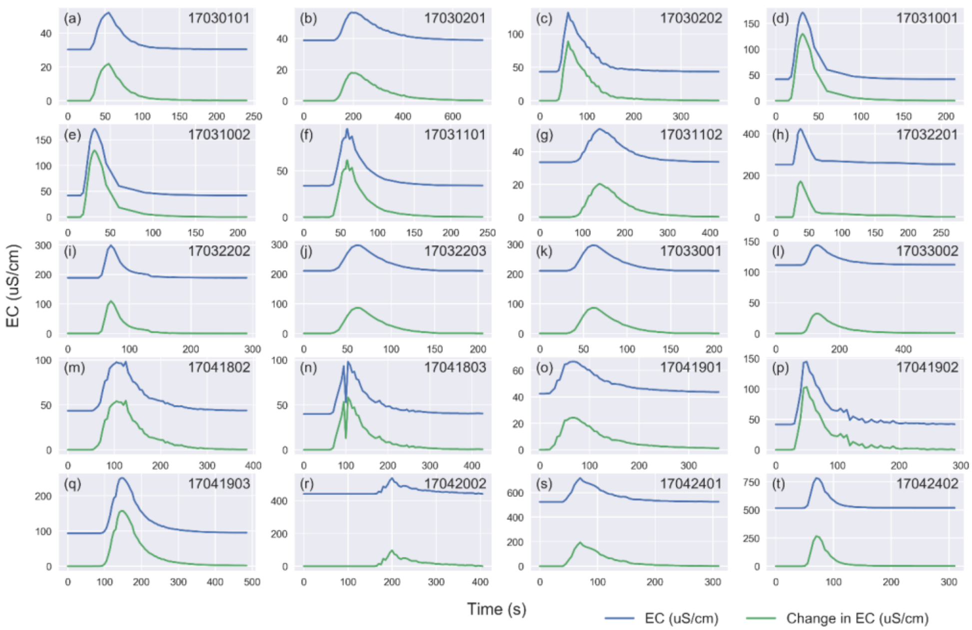

~~Figure 2: Plots of EC (μS cm^{-1}; blue trace) and change in EC (μS cm^{-1}; green trace) as a function of time (s) for the 20 salt dilution evaluation measurements. Measurement ID (Msmt ID; Table 1) shown at the top right of each subplot (i.e. a through t).~~

~~**3.2 Flow and calibration coefficient (k) results**~~

~~**3.2.1 Flow scatter plots**~~

~~Scatter plots between reference and observed flows with linear regressions forced through the origin had slopes of 1.05, 1.01, and 1.26 for float, salt dilution, and Bernoulli methods, respectively (Fig. 3). A slope of one represents zero systematic bias, whereas values over one represent positive bias, and values less than one represent negative bias. Therefore, for all the methods evaluated we observed different degrees of positive bias. R-squared values were 0.90, 0.98, and 0.61 for float, salt dilution, and Bernoulli methods, respectively (Fig. 3). R-squared values represent the goodness of fit between the regression and the observed data; values closer to one represent a better fit. This can also be seen by the observations for salt dilution plotting closest to the regression line, whereas float and Bernoulli points in general plot farther away from the regression line.~~

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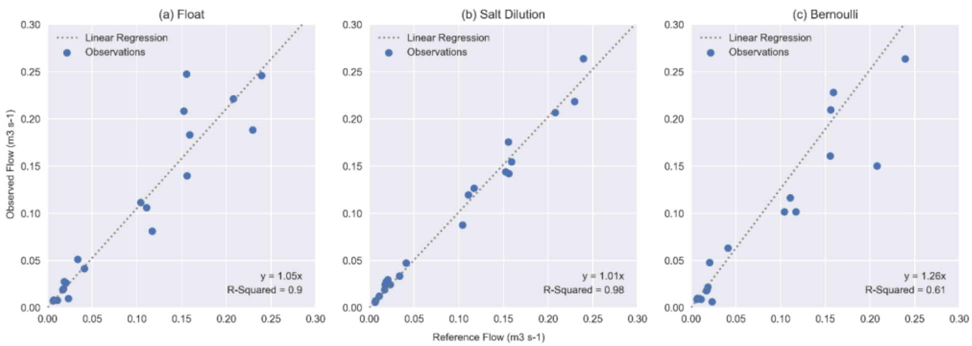

~~Figure 3: Scatter plots between reference flow and observed flow for (a) float, (b) salt dilution, and (c) Bernoulli. Note there is one Bernoulli measurement point (17033002) that is outside of the plot space shown (fixed from 0.0 to 0.3 for consistency). Linear regressions and r-squared values shown on the bottom right of each sub-plot.~~

~~3.2.2 Flow error correlations~~

~~We found statistically significant correlations (n = 20, p = 0.1, r > 0.378) between the absolute value of percent error for float and average velocity (Avg Vel; sub-plot b; r = -0.48) and salt dilution percent error and reference flow (Q Ref; sub-plot e; r = -0.44) (Fig. 4). In both cases, the correlation coefficient was negative, indicating an inverse relationship between the variables. No statistically significant correlations were observed between the remaining pairs of variables.~~

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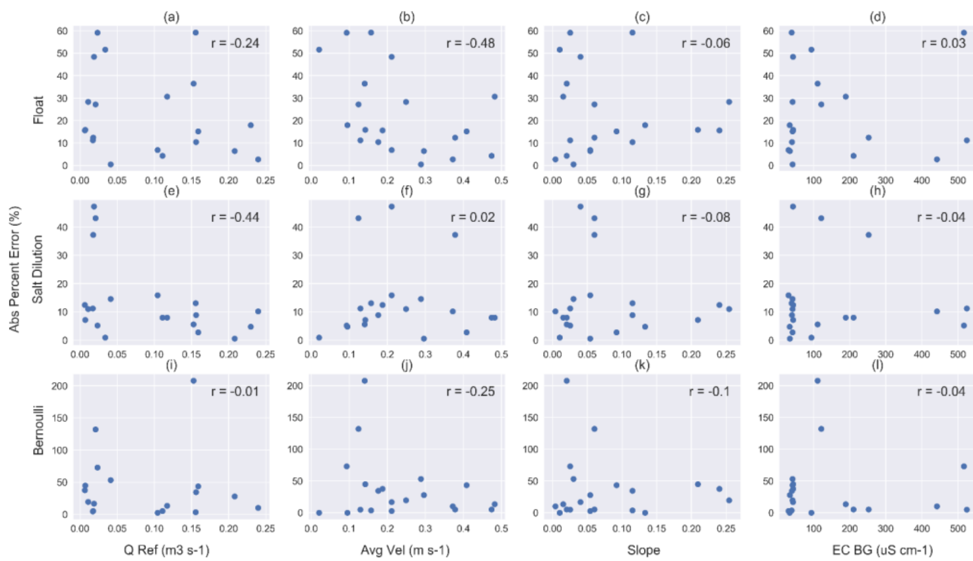

~~Figure 4: Scatter plots between reference flow (Q Ref; m^3 s^{-1}), average water velocity (Avg Vel; m s^{-1}), slope, and background EC (EC BG; µS cm^{-1}) and absolute value (Abs) of percent errors for float, salt dilution, and Bernoulli. Pearson's r values shown on the upper right of each subplot (i.e. a through l).~~

~~3.2.3 Salt dilution calibration coefficient (k) results~~

~~The mean calibration coefficient (k) from measurements performed in the field was 2.81 x 10^{-6} ± 2.66 x 10^{-7} (95 % confidence interval; n = 10, min = 2.57 x 10^{-6}, max = 3.05 x 10^{-6}, std dev = 1.33 x 10^{-7}). We used mean k to compute salt dilution flows for the remaining 10 measurements. We found statistically significant correlations (n = 10, p = 0.1, r > 0.549) between the calibration coefficient (k) and Longitude (r = 0.60) and Elevation (r = 0.61; Fig. 5). In both cases, the correlation coefficient was positive, indicating a direct relationship between the variables. No statistically significant correlations were observed between the remaining pairs of variables.~~

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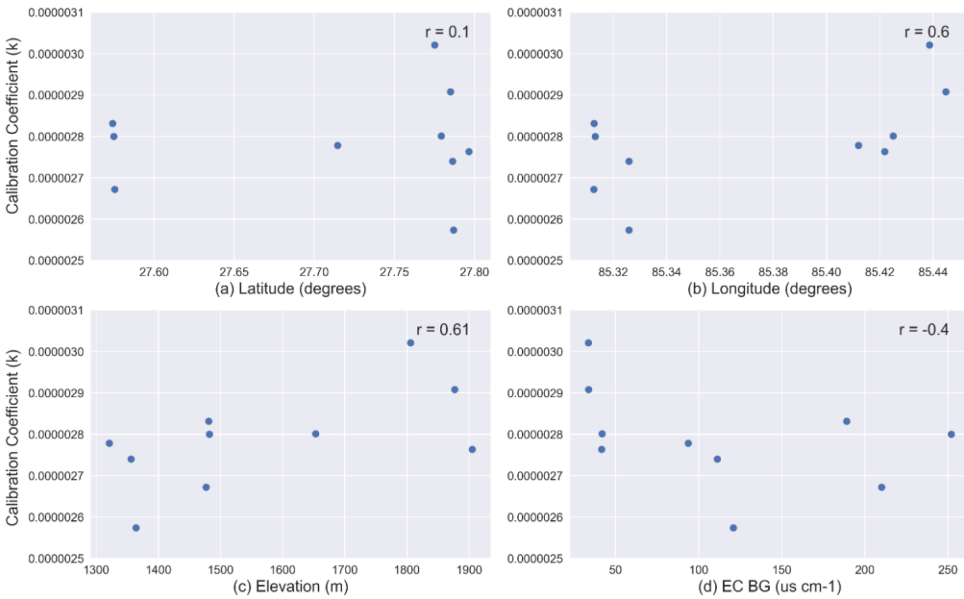

~~Figure 5: Scatter plots between (a) Latitude in degrees, (b) Longitude in degrees, (c) Elevation in meters above mean sea level (m), and (d) background EC in µS cm^{-1} and the salt dilution calibration coefficient (k). Pearson's r values shown on the upper right of each sub-plot.~~

3.2 Citizen scientist evaluation results (Phase 2)

Phase 2 citizen scientist evaluations (Fig. 3) were performed at seven sites in the Dhobi watershed in the north (Fig. 3.b; D1 to D7) and eight sites in the Nakkhu watershed in the south (Fig. 3.c; N1 to N8). Measurement sites in the Dhobi watershed were pool and drop stream types, with slopes ranging from 0.076 to 0.148 m m^{-1}. Streambeds for these sites were predominantly cobles, gravels, and sands. Smaller tributaries measured in the Nakkhu watershed (N2, N4, and N6) were also pool and drop streams types with slopes of 0.105, 0.091, and 0.055 m m^{-1}, respectively. The remainder of the sites in the Nakkhu watershed were pool and riffle stream types with slopes ranging from 0.020 to 0.075 m m^{-1}. Salt dilution calibration coefficients (k) averaged 2.95E-06 and ranged from 2.62E-06 to 3.42E-06. Flows evaluated ranged from 4.2 to 896 L s^{-1}. Absolute errors for "expert" measurements averaged 41, 21, and 43 %, while biases for all methods were positive,

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averaging 41, 19, and 40 % for float, salt dilution, and Bernoulli methods, respectively (Table 4 and Fig. 4). Standard deviations of "expert" errors were 34, 26, and 51 % for float, salt dilution, and Bernoulli methods, respectively.

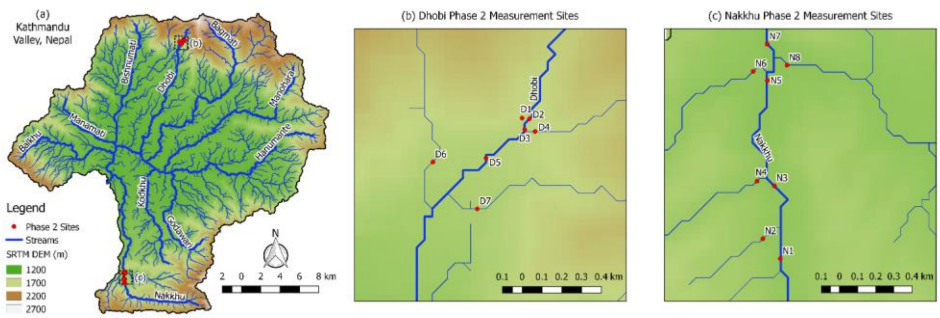

Figure 3: Map showing topography of the Kathmandu Valley, stream network, and locations of phase 2 measurement sites (a). Names of the ten historically perennial tributaries are shown. Panel (b) shows an enlarged view of the upper Dhobi watershed where Phase 2 measurements D1 through D7 were performed. Panel (c) shows an enlarged view of the middle Nakkhu watershed where Phase 2 measurements N1 through N8 were performed. Measurement sites are labelled with Phase 2 Site IDs.

Table 4: Summary of (Phase 2) measurement comparison sites including salt dilution calibration coefficient (k), resulting reference flows (Q Reference), "expert" streamflow measurement method flows (Q Float, Q Salt, and Q Bernoulli), and corresponding "expert" measurement errors. Date and time associated with "expert" measurements. Latitude and longitude in reference to the WGS84 datum. All flow values shown are shown in L s^{-1} rounded to the nearest integer for values greater than or equal to 10 and to the nearest tenth place for values less than 10. Percent differences (errors) calculated using Q Reference (FlowTracker) as the actual flow. Data summarized at the bottom with average, minimum (min), maximum (max), and standard deviation (std dev). Note that averages (avg *) shown in the summary area near the bottom for the last three columns (i.e. percent errors) include averages of absolute values of percent errors (i.e. absolute errors) shown underlined in parentheses. Average k (2.95E-06) was used to compute Q salt for all Phase 2 and 3 sites.

Site ID	Date	Time	Latitude	Longitude	k (cm µS^{-1})	Slope (m m^{-1})	Q Reference (L s^{-1})	Expert Q Float (L s^{-1})	Expert Q Salt (L s^{-1})	Expert Q Bernoulli (L s^{-1})	Expert % Error Float	Expert % Error Salt	Expert % Error Bernoulli
D1	18/09/18	14:42	27.79246	85.37166	2.76E-06	0.099	137	150	134	122	10	-2	-11
D2	18/09/18	15:46	27.79263	85.37158	2.70E-06	0.091	253	364	258	356	44	2	41
D3	18/09/18	13:41	27.79213	85.37136	2.62E-06	0.076	417	551	500	396	32	20	-5
D4	18/09/18	12:44	27.79189	85.37162	2.69E-06	0.139	78	77	84	81	-1	7	3
D5	19/09/18	10:18	27.79071	85.36966	2.80E-06	0.148	184	243	207	287	32	12	56
D6	19/09/18	11:52	27.79052	85.36695	3.42E-06	0.134	36	84	47	88	132	30	146
D7	19/09/18	13:11	27.78791	85.36912	2.87E-06	0.126	55	60	86	52	10	56	-6
N1	20/09/18	17:35	27.56525	85.31356	2.90E-06	0.025	437	699	548	540	60	25	24
N2	20/09/18	16:59	27.56615	85.31214	3.37E-06	0.105	4.2	7.3	4.0	11	73	-5	158

N3	20/09/18	16:02	27.56935	85.31277	2.93E-06	0.075	340	392	548	445	15	61	31
N4	20/09/18	15:21	27.56916	85.31200	2.71E-06	0.091	25	40	27	33	61	8	33
N5	20/09/18	12:56	27.57328	85.31263	3.08E-06	0.022	407	607	700	545	49	72	34
N6	20/09/18	13:33	27.57408	85.31226	2.95E-06	0.055	105	151	103	136	44	-2	30
N7	20/09/18	11:50	27.57558	85.31269	3.35E-06	0.044	896	944	814	839	5	-9	-6
N8	20/09/18	10:59	27.57516	85.31345	3.11E-06	0.020	270	382	284	453	41	5	68
				avg * ->	2.95E-06	0.083	243	317	290	292	41 (41)	19 (21)	40 (43)
				min ->	2.62E-06	0.020	4.2	7.3	4.0	10.8	-1	-9	-11
				max ->	3.42E-06	0.148	896	944	814	839	132	72	158
				std dev ->	2.62E-07	0.043	235	281	265	244	34	26	51

Box plots of CS Flow group errors combined with "expert" measurement errors for float (a), salt dilution (b), and Bernoulli (c) methods show that errors, for both "expert" and CS Flow groups, are least for the salt dilution method (Fig. 4). The number of CS Flow group measurements used to develop individual box plots ranged from 6 to 12 for each site and totalled 117 for all 15 sites. Two groups measured site D3 twice, so even though there were only 10 groups, there were 12 measurements available for comparison for this site. For the remainder of sites (except N5), problems with either capturing, compressing, uploading, or interpreting the video of EC used for determining salt dilution flow limited the number of usable measurements to less than the number of groups (i.e. 10). Absolute errors for CS Flow group measurements averaged 63, 28, and 131 %, while biases for all methods were positive, averaging 52, 7, and 127 % for float, salt dilution, and Bernoulli methods, respectively. Standard deviations of CS Flow group errors were 82, 36, and 225 % for float, salt dilution, and Bernoulli methods, respectively.

For the float method (Fig. 4.a), 13 median CS Flow group errors were positive, while two sites (i.e. D3 and N7) were negative. Float "expert" errors (i.e. red circles) were within the inner-quartile range (IQR; blue boxes between the first and third quartile) of CS Flow group errors for 10 out of 15 sites. One float "expert" error and 21 CS Flow group errors were over 100 %. Float error medians and distributions were more variable in the Dhobi watershed than the Nakkhu watershed. For the salt dilution method (Fig. 4.b), seven median CS Flow group errors were positive, while eight were negative. Salt dilution "expert" errors (i.e. red circles) were within the IQR of CS Flow group errors for 7 out of 15 sites. Zero salt dilution "expert" errors and two CS Flow group errors were over 100 %. Salt dilution error distributions were more compact for the Dhobi watershed compared to the Nakkhu watershed. For the Bernoulli method (Fig. 4.c), all 15 median CS Flow group errors were positive. Bernoulli "expert" errors (i.e. red circles) were within the IQR of CS Flow group errors for 3 out of 15 sites. Two Bernoulli "expert" errors and 50 CS Flow group errors were over 100 %. Similar to float results, Bernoulli error medians and distributions were more variable in the Dhobi watershed than the Nakkhu watershed.

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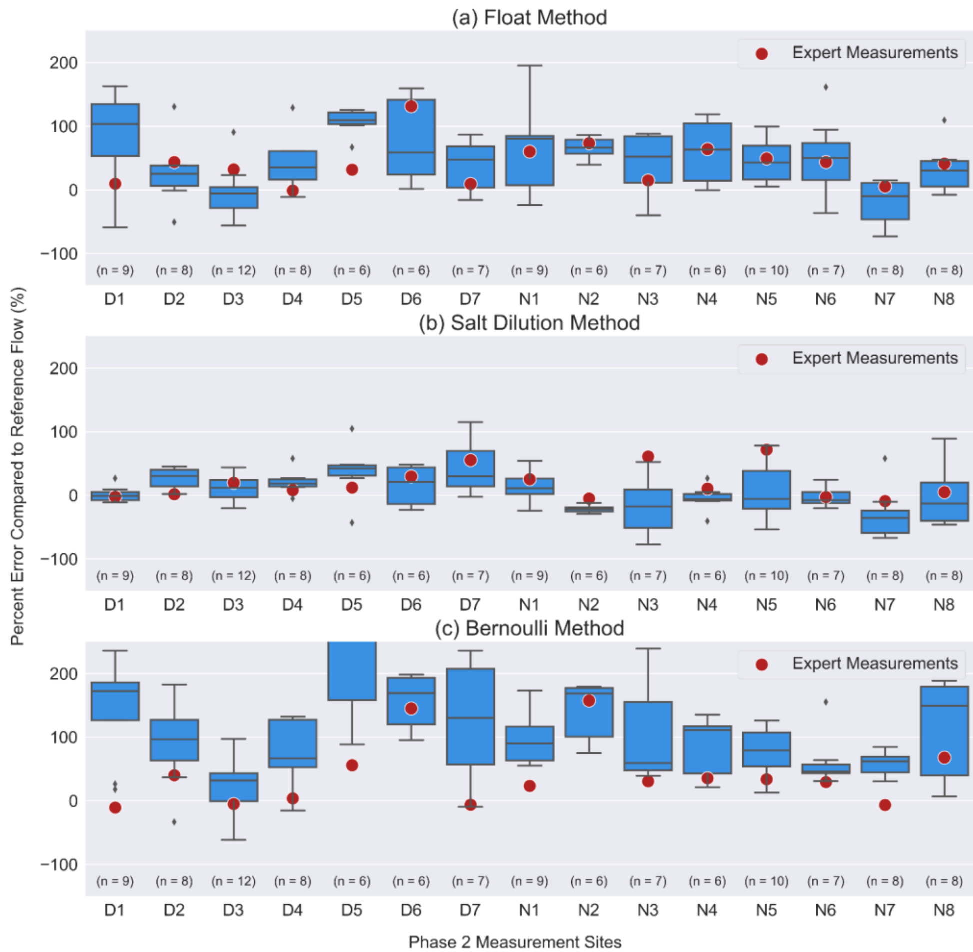

Figure 4: Box plots showing distribution of CS Flow group percent errors compared to reference flows for (a) float, (b) salt dilution, and (c) Bernoulli streamflow measurement methods. The 15 Phase 2 measurement sites (i.e. D1 to D7 in the Dhobi watershed and N1 to N8 in the Nakkhu watershed) are shown on the horizontal axes. To facilitate comparison between sub-panels, vertical axes are fixed from -150 to 250 percent. Percent errors for "expert" measurements for each site and method are shown as red circles. Sample sizes for each method and each site are shown in parentheses above each site label (e.g. (n = 9)). Boxes show the inner-quartile range between the first and third quartiles of the dataset, while whiskers extend to the minimum and maximum values of the distribution, except for points that are determined to be "outliers" using a method that is a function of

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1.5 times the inter-quartile range (Anon 2018). In certain cases, portions of the error distribution are outside of the fixed range (e.g. Site D5 for Bernoulli (c) method).

Overall, citizen scientists ranked the float method most favourably (43.2 % of Rank 1 selections; average of blue bars) compared to Bernoulli and salt dilution methods, at 30.3 and 26.5 %, respectively (Fig. 5). In contrast, citizen scientists ranked the salt dilution method least favourably (64.0 % of Rank 3 selections; average of tan bars) compared to Bernoulli and float methods, at 18.6 and 17.4 %, respectively. Most citizen scientists (72.7 %) thought the float method required the least amount of training (Q1), followed by the Bernoulli and salt dilution methods. Citizen scientists thought the Bernoulli method required the smallest investment in equipment ~~least amount of training~~ (45.5 %; Q2), the fewest number of citizen scientists (54.5 %; Q3), and least amount of data recording (42.4 %; Q4). Additionally, citizen scientists found the float method to be the least complex (48.5 %; Q5), most enjoyable (60.6 %; Q6), and safest (42.4 %; Q7) method. Finally, most citizen scientists (75.8 %) thought the salt dilution method was most accurate (Q8), followed by the float and Bernoulli methods. The complete results from the survey are included as supplementary material.

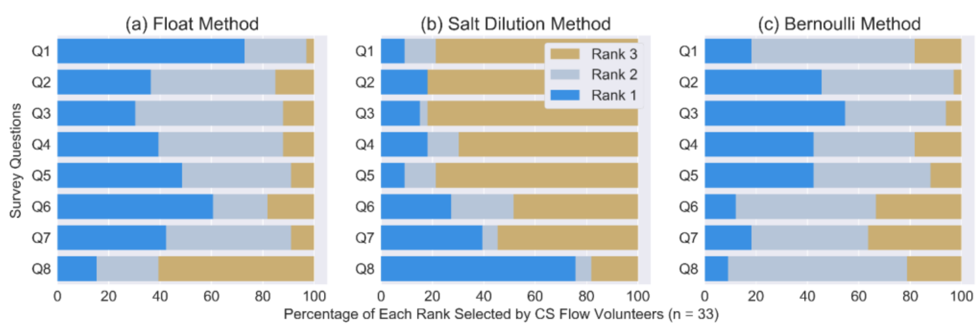

Figure 5: Results of the CS Flow group perception questions for (a) float, (b) salt dilution, and (c) Bernoulli methods. Questions Q1 through Q8 are shown on the vertical axis. Percentage of each rank selected by CS Flow citizen scientists (n = 33) are shown on the horizontal axis. Questions were worded so that in all cases, a rank of 1 was most favourable and 3 was least favourable. Questions are as follows (also included in Sect. 2.2.2): Q1 - Required training (1 least and 3 most); Q2 - Cost of equipment (1 least and 3 most); Q3 - Number of citizen scientists required (1 least and 3 most); Q4 - Data recording requirements (1 least and 3 most); Q5 - Complexity of procedure (1 least and 3 most); Q6 - Enjoyability of measurement (1 most enjoyable and 3 least enjoyable); Q7 - Safety (1 safest and 3 least safe); Q8 - Accuracy (1 most accurate and 3 least accurate).

3.3 ~~3.3.~~ Citizen scientist ~~CS Flow campaign results~~application results (Phase 3)

Observed flows from the CS Flow campaign (n = 131 pre-monsoon; n = 133 post-monsoon) were distributed among the 10 perennial headwater catchments of the Kathmandu Valley and ranged from 0.4 to 425 L s^{-1} and 1.~~5~~1 to 1804 L s^{-1} in the pre and post-monsoon, respectively (Fig. 6.a and 6.b).~~From the 15th to the 21st of April 2018, 20 students from Khwopa College of Engineering in Bhaktapur, Nepal joined S4W-Nepal's CS Flow campaign. After four hours of training (i.e. two hours classroom and two hours in the field), the student volunteers performed 145 salt dilution streamflow measurements in the 10~~

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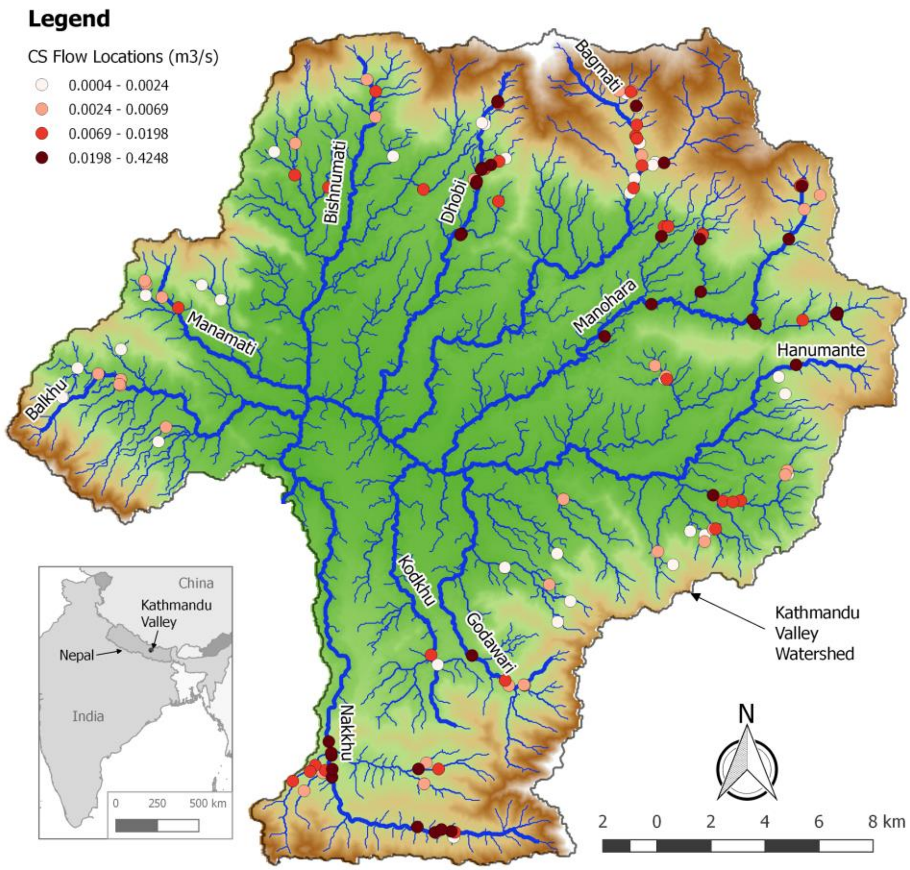
~~sub-watersheds of the Kathmandu Valley (Fig. 6). Observed flows ranged from 0.0004 to 0.425 $m^3 s^{-1}$ (a summary of the measurement data is included as supplementary material).~~

The three locations in the Kathmandu Valley that the Nepal Department of Hydrology and Meteorology (DHM) measures either water levels or flows (gauges) are included on Fig. 6.a and 6.b to illustrate the difference in spatial resolutions between the two datasets. Note that only one of the three DHM gauging stations is in a headwater catchment (i.e. Bagmati). Histograms of flow (Fig 6.c and 6.d) and EC (Fig. 6.e and 6.f) show the increase in flows and the decrease in EC from pre to post-monsoon.



Legend
CS Flow Locations (m3/s)
0.0004 - 0.0024
0.0024 - 0.0069
0.0069 - 0.0198
0.0198 - 0.4248
Bagmati
Bishnumati
Dhobi
Manamati
Balkhu
Manohara
Hanumante
Kodkhu
Godawari
Nakkhu
Kathmandu
Valley
Watershed
China
Kathmandu
Valley
Nepal
India
0
250
500 km
N
2
0
2
4
6
8 km

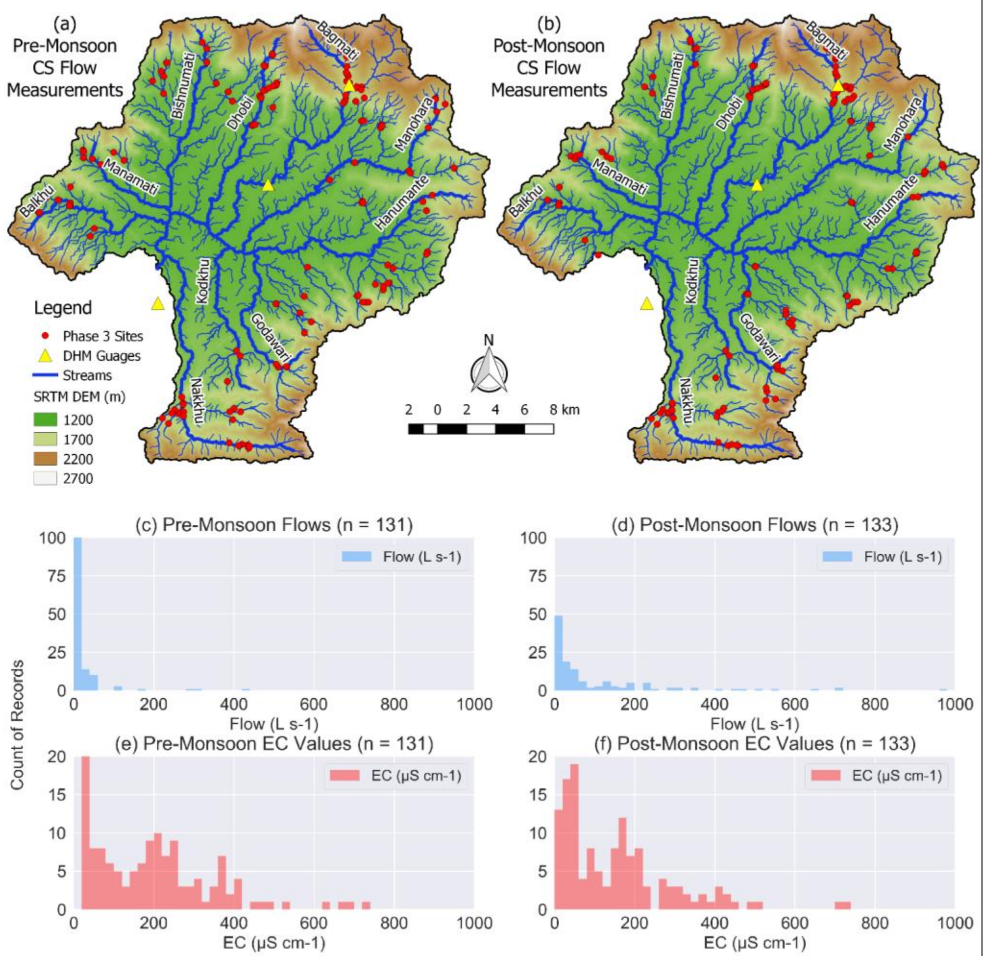


Figure 6~~6~~6: CS Flow ~~Campaign~~ campaign measurement locations (n = 131 pre-monsoon; n = 133 post-monsoon~~n = 145~~) within the Kathmandu Valley for (a) pre and (b) post-monsoon. Histograms show distributions of measured flows in L s^{-1} ((c) and (d)) and EC in µS cm^{-1} ((e) and (f)). Bins are set to 20 units wide for both flow and EC. Three flow measurements for the post-monsoon (d) above 1000 L s^{-1}: 1059, 1287, and 1804. Three Department of Hydrology and Meteorology (DHM) gauging stations shown as yellow triangles.~~Circular symbol colors are graduated by observed flow rate, categorized by quartile. Larger flows (i.e. darker symbols) were observed on the mainstems (i.e. wider blue lines) of the 10 tributaries of Bagmati River in the Kathmandu Valley.~~

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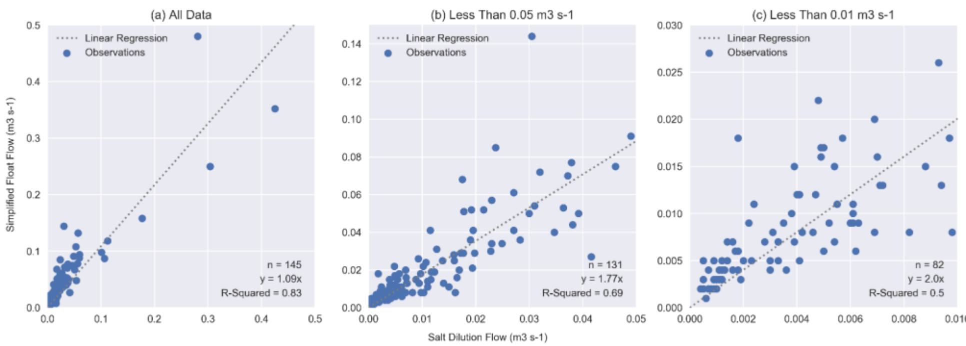
~~Scatter plots between flow estimates from the simplified float method (used to calculated salt dosage) and the salt dilution flow results show that systematic differences increase as the observed flow rate decreases (Fig. 7).~~



~~**Figure 7: Scatter plots between salt dilution measurements on the horizontal axis and simplified float estimates on the vertical axis. All data are shown on subplot (a), flows below 0.05 m^3 s^{-1} are included on subplot (b), and flows below 0.01 m^3 s^{-1} are shown on subplot (c). A linear fit with corresponding r-squared values are shown. Note that the vertical axis scales for subplots (b) and (c) are fixed at three times the horizontal axis scale to ensure that all data are visible.**~~

~~We identified five locations where S4W-Nepal had performed FlowTracker measurements that could be used as reference flows within roughly one month (plus or minus) of the CS Flow salt dilution measurements (Table 2). Comparable flows ranged from 0.012 and 0.111 m^3 s^{-1}. The average error between CS Flow salt dilution and S4W-Nepal FlowTracker measurements was -6.3 %, with a standard deviation of 11.5 %. Linear regression forced through the origin between reference flows and CS Flow measurements had a slope of 0.90 with an r-squared value of 0.97.~~

~~**Table 2:** ***Comparison between CS Flow salt dilution and S4W-Nepal FlowTracker measurements. Five measurements were identified for evaluation. In one case (i.e. CS Flow Msmt Date 4/16/2018 10:03), a linear interpolation between two S4W-Nepal measurements (i.e. 3/15/2018 7:15 and 5/23/2018 14:23) was made because measurements for both March and May were available. Data summarized at the bottom with average, minimum (min), maximum (max), and standard deviation (std dev).***~~

~~S4W-Nepal SiteID~~	~~CS Flow Msmt Date~~	~~S4W-Nepal Msmt Date~~	~~CS Flow Salt Dilution Q (m3 s-1)~~	~~S4W-Nepal FlowTracker Reference Q (m3 s-1)~~	~~% Difference~~
~~DB02~~	~~4/16/2018 10:03~~	~~3/15/2018 7:15 and 5/23/2018 14:23~~	~~0.0529~~	~~0.0492~~	~~7.5%~~
~~BM02~~	~~4/16/2018 13:22~~	~~3/15/2018 9:49~~	~~0.0169~~	~~0.0172~~	~~-1.7%~~
~~NA02~~	~~4/18/2018 13:28~~	~~3/31/2018 4:39~~	~~0.0940~~	~~0.1110~~	~~-15.3%~~
~~BA01~~	~~4/20/2018 11:30~~	~~3/30/2018 9:24~~	~~0.0090~~	~~0.0118~~	~~-23.7%~~
~~NK03~~	~~4/18/2018 13:57~~	~~5/16/2018 12:22~~	~~0.0461~~	~~0.0454~~	~~1.5%~~
		~~average ->~~	~~0.0438~~	~~0.0469~~	~~-6.3%~~
		~~min ->~~	~~0.0090~~	~~0.0118~~	~~-23.7%~~
		~~max ->~~	~~0.0940~~	~~0.1110~~	~~7.5%~~
		~~std dev ->~~	~~0.0301~~	~~0.0353~~	~~11.5%~~

4 Discussion

~~4~~

4.1 ~~Preferred measurement method~~Initial evaluation discussion (Phase 1)

Our first research question was: *Which simple streamflow measurement method provides the most accurate results when performed by "experts?"* Based on Phase 1 "expert" measurements, we found that salt dilution had the lowest absolute error (i.e. 15 %), compared to float and Bernoulli methods (i.e. 23 and 37 %, respectively; Table 3).

The largest salt dilution errors occurred for reference flows of 21 L s^{-1} or less, while float and Bernoulli errors appeared to be more evenly distributed through the range of observed flows. Because salt dilution measurements of low flows require less salt and water, it is possible that larger relative measurement errors caused while measuring these small quantities led to larger overall measurement errors. However, this is not substantiated in Phase 2 results, so additional research is required in this area.~~Based on 20 flow measurements performed in this study, we concluded that the salt dilution method will (1) provide the most accurate streamflow data (at least for the range of flows observed), and (2) will be the easiest method for citizen scientists to repeat in the field with limited amounts of training and equipment (see Section 4.4 on citizen scientist repeatability).~~

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Our experience in the field was that float velocity measurements in slow moving and shallow areas were difficult to perform. The combination of turbulence and boundary layer impacts from the streambed and the overlying air mass often made floating objects on the surface travel in non-linear paths, adding uncertainty to distance and time measurements. In the literature, challenges with applying the float method in shallow depths is supported by USBR (2001) and Escurra (2004), who showed that uncertainty in surface velocity coefficients (i.e. the ratio of surface velocity to actual mean velocity of the underlying water column; C from Eq. (1)) increased as depth decreased, especially below 0.3 m.

~~While all flow measurement methods evaluated had positive biases, salt dilution showed the closest agreement to the reference flow with an average over estimation of only one percent (based on the linear regression), followed by float and Bernoulli at 5 and 25 %, respectively (Fig. 3). The standard deviation for errors was 17 % for salt dilution, and 29 and 62 % for float and Bernoulli, respectively. Additionally, r-squared values indicated that salt dilution had the least amount of variance from the trend line (i.e. closest to one).~~

~~Only three salt dilution measurements (i.e. 17032201, 17041901, and 17033001) had percent differences larger than 20 %, and these were all positively biased in relatively small streams (flows between 0.018 and 0.021 $m^3 s^{-1}$). While we can't be certain, we suggest that these errors may be due hyporheic exchanges that removed some salt solution from the measurement reach before lateral and vertical mixing could fully occur. In other words, it is possible that some of the salt solution became "underflow" shortly after the injection point and did not return to the surface stream prior to the EC measurement location. As observed, this "removal" of salt solution would lead to a systematic overestimation of flow. If these three measurements are removed, the mean and standard deviation for salt dilution method percent differences become 2 and 9 %, respectively. These percent differences fall within the expected range of uncertainty presented in the literature for salt dilution gauging (Day 1976; USBR 2001; Moore 2004a; Herschy 2014). Excluding these three errors, and assuming errors are normally distributed, we expect that salt dilution measurements will be within roughly ±18 % (95 % confidence interval).~~ The impacts of shallow depths on surface velocity coefficient C should be the focus on additional research.

A primary challenge we experienced with Bernoulli measurements was keeping the flat plate at the same vertical location while rotating the plate from parallel to perpendicular to the flow direction (Sect. 1.3.3). This was usually due to the bottom of the flat plate being set on a streambed consisting of sands and gravels that could be easily disturbed during rotation. Slow water velocities, and correspondingly small changes in Bernoulli depths (Eq. 4) further compounded this issue. Adding a circular metal plate to the bottom of the flat plate used for Bernoulli depth measurements could help minimize these uncertainties.

Based on the 10 measured k values in Phase 1, using an average k for all salt dilution measurements caused the largest percent difference in salt dilution flow (Eq. 2) for site 7 (8.6 % increase in flow) followed by site 19 (7.6 % decrease in flow). For Phase 2, using average k values for all salt dilution measurements caused the largest percent difference in salt dilution flow (Eq. 2) for site D6 (13.7 % decrease in flow) followed by site D3 (12.6 % increase in flow). Because observed absolute error distributions from Phase 1, and especially Phase 2, are larger than errors introduced by using average k values (sometimes by more than an order of magnitude), we do not think our overall findings are negatively impacted by using average k values. However, because of the sensitivity of salt dilution measurements to k (Eq. 2), future work should focus on improving understanding of the variables affecting k. Specifically, spatial and temporal variability in k due to changes in stream water chemistry should be investigated prior to applying the salt dilution methodology described in this paper in other areas.

4.2 Citizen scientist evaluation discussion (Phase 2)

Our second research question was: *Which simple streamflow measurement method provides the most accurate results when performed by citizen scientists?* Based on Phase 2 citizen scientist measurements, we found that salt dilution had the lowest absolute error (i.e. 28 %) compared to float and Bernoulli methods (i.e. 63 and 131 %; Fig. 4).

While absolute error distributions for citizen scientists followed the same trend to that of "expert" measurements, the relative increases in errors for float (41 to 63 %; increase of 54 %) and Bernoulli (43 to 131 %; increase of 205 %) were larger than that of salt dilution (21 to 28 %; increase of 33 %). This could be due in part to the fact that salt dilution measurement errors may be less sensitive to a lack of field data collection experience. For example, as long as turbulent mixing conditions are present (which can be controlled by proper site during the experimental design phase), citizen scientists can primarily introduce errors into salt dilution measurements by (1) making mistakes in measurement or recording of amounts of salt and/or water used to prepare tracer solutions, (2) not thoroughly mixing tracer solution until all salt is dissolved, (3) not providing enough distance between salt injection and EC measurement points (recommended as 25 stream widths by Day 1977; Butterworth et al. 2000; Moore 2005), or (4) recording videos of EC changes that are difficult to read. Each of these sources of error can be minimized by implementing relatively easy to follow protocols like "be sure to mix the salt and water until you can't see the salt any longer." In contrast, while performing float and Bernoulli measurements, citizen scientists need to accurately characterize (1) average stream depth, (2) stream width, and (3) average water velocity. Characterizing average depth and velocity requires several individual measurements, each coming with the chance of introducing measurement errors. Additionally, selecting the number of sub-sections required, and selected representative locations for each of these sub-sections can be difficult, even for people with extensive streamflow data collection experience. These factors may help explain the wider error distributions observed in float and Bernoulli methods compared to salt dilution (Fig. 4). Additional training might also help to close the observed differences between salt dilution error distributions and that of float and Bernoulli methods.

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Our third research question was: *What are citizen scientists' perceptions of the required training, cost, accuracy, etc. of the evaluated simple streamflow measurement methods?* Based on a survey of 33 of citizen scientists, we found that volunteers ranked the float method most favourably (43.2 % of Rank 1 selections) compared to Bernoulli and salt dilution methods, at 30.3 and 26.5 %, respectively (Fig. 5).

Regarding question number 4 from the perception survey (i.e. data recording requirements), it is interesting to note that salt dilution received the least favourable ranking, meaning that citizen scientists perceived salt dilution to require the greatest amount of data. Our perception was that salt dilution, in terms of individual pieces of information, requires the least amount of data recording. This ranking may be explained by either (1) the amount of meta data collected about salt dilution measurements (i.e. GPS and photos of salt injection and EC measurement locations; see Sect. 2.2.2 for details) or by (2) citizen scientists' perception of using a digital EC meter and smartphone video as recording lots of individual pieces of data, when in some ways a video can be thought of as a single observation. Whereas results from float and Bernoulli method measurements are available immediately in the ODK from, the post processing requirements of EC breakthrough curve data to solve for salt dilution flow may also lead to the perception that salt dilution measurements have higher data recording requirements.

Citizen scientists ranked float method safest, followed by salt dilution, and finally Bernoulli. We found this result to be somewhat counter intuitive, because salt dilution is the only method that can be performed without entering the stream, whereas for float and Bernoulli measurements the entire stream must be waded across to get depth and velocity data. Because the perception survey was performed after Phase 2 evaluations where all three methods were performed consecutively, it may not have been obvious to citizen scientists that salt doses could be obtained without entering the stream from visual estimates of channel width, depth, and water velocity.

In terms of perceived measurement accuracy (question 8), 75.8 % of citizen scientists ranked salt dilution as the most accurate method. This ranking was performed before any quantitative results were reviewed. Our experience is that often reading a value from a digital meter gives a sometimes unfounded sense of measurement accuracy. Salt dilutions' perceived accuracy may be due to it being the only method that directly involves a digital measurement device (i.e. EC meter).

"Expert" absolute errors for float, salt dilution, and Bernoulli increased from 23, 15, and 37 % in Phase 1 to 41, 21, and 43 % in Phase 2. For the float method, this increase in error may be partially explained by the overall increase in flows from pre-monsoon (Phase 1; average reference flow of 92 L s^{-1}) to post-monsoon (Phase 2; average reference flow of 243 L s^{-1}). Our experience was that increased flow and velocity in high gradient headwater streams made it more difficult to perform float measurements. This was due mostly due to an increase in turbulence resulting in more non-linear flow lines and increased

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relative measurement uncertainty for shorter float times (assuming distances were held constant). For the Bernoulli method however, our hypothesis was that increased velocities would on average reduce measurement errors, because of decreased relative measurement uncertainty for larger Bernoulli depth changes. This hypothesis however was not supported by the data. The challenge of pulsing flows which require citizen scientists to visually average short period (i.e. seconds or less) water level fluctuations may also counteract the otherwise larger Bernoulli depth changes. We do not have any explanations for the overall increase in salt dilution method absolute error from 15 to 21 % from Phase 1 to Phase 2. Unlike the Phase 1 results, we also do not see a concentration of larger errors at the lower reference flows in Phase 2.

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4.3 Citizen scientist application ~~results~~discussion (Phase 3)

To proceed with Phase 3, we had to select a preferred simple streamflow measurement method. Based on the results from Phases 1 and 2, the salt dilution method had the lowest absolute errors, biases, and error standard deviations for both "experts" and citizen scientists. Therefore, from an accuracy perspective, salt dilution was the preferred approach. However, the results of our perception survey showed that citizen scientists thought the float method was most enjoyable (Q6) and required the least amount of training (Q1). Another important consideration was that salt dilution is the only method that doesn't require citizen scientists to enter and cross the stream, and therefore can be safely performed over a broader range of flow conditions. While the enjoyment of measurements is an important motivational factor for citizen scientists, we concluded that accuracy and safety were ultimately more important. Considering all these factors, we selected the salt dilution method as the preferred approach.

Finally, our fourth research question was: *Can citizen scientists apply the selected streamflow measurement method at a larger scale?* Based on measurements from pre (n = 131) and post-monsoon (n = 133) in the Kathmandu Valley, citizen scientists are able to apply salt dilution streamflow measurements at a larger scale; however, challenges of recruiting, training, and motivating citizen scientists, along with data management issues require further investigation. The CS Flow campaigns provided us with a unique opportunity to evaluate the preferred salt dilution streamflow measurement method at a larger scale. In addition to the valuable streamflow data that will help us characterize the water supply situation in the Kathmandu Valley with greater precision for pre and post-monsoon periods, we also learned several practical lessons about how to apply citizen science-based streamflow measurements at a larger scale. For example, managing EC change videos can be a significant challenge if videos are recorded at a smartphones' native resolution. For example, each minute of high definition video can be nearly 100 MB. Uploading such large files, and subsequently storing and accessing them can be challenging and costly. These difficulties can be solved by improved training and protocols regarding video collection settings and, when necessary, video compression.

~~4.2 Measurement error correlation~~

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~~In Fig. 4, three "outlier" percent errors for salt dilution measurements were seen in the middle row of sub-plots (5 through 8) as clusters of three points towards the top of each sub-plot. After removing these points, the Pearson's r value decreased to~~

~~0.26, and the correlation became statistically insignificant (n = 20, p = 0.1, r > 0.378). Therefore, we are cautious to conclude that error in salt dilution measurements decreases as the amount of streamflow increases. Errors in salt dilution measurements appeared to be uncorrelated with the other variables evaluated (e.g. average velocity, slope, and~~ ~~EC_{BG}~~~~).~~

~~The other observed statistically significant correlation was an inverse relationship between average velocity and error in float measurements. Our experience in the field validated that slow moving (and shallow) float velocity measurements were difficult to perform. The combination of turbulence and boundary layer impacts from the streambed and the overlying air mass often made floating objects on the surface travel in non-linear paths, adding uncertainty to distance and time measurements. Challenges with applying the float method in shallow depths was supported USBR (2001) and Escurra (2004), who showed that uncertainty in surface velocity coefficients (i.e. the ratio of surface velocity to actual mean velocity of the underlying water column) increased as depth decreased, especially below 0.3 m.~~

~~4.3 Salt dilution calibration coefficient (k)~~

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~~Moore (2005) suggests that k depends on (1) the ratio of salt and water in the tracer solution and (2) the chemical composition of the stream water. To minimize variability in k due to changes in salt concentration, a fixed ratio of salt to water (e.g. 1 to 6 by mass) should be consistently used to prepare tracer solutions (as it was during this investigation). Significant correlations observed between k and longitude and elevation may be due to changes in water chemistry that co-vary with these independent variables. Measurements performed in the northeastern portion (i.e. higher longitude) of the Kathmandu Valley were higher in altitude. Geology in the north of the Kathmandu Valley is a mixture of weathered igneous and metamorphic parent material (e.g. gneiss, phyllite, schist, etc.). Geology surrounding measurements in the southwest of the Kathmandu Valley is dominated by sedimentary and slightly metamorphosed deposits of sand, silt, and clay (Shrestha et al. 2012). These differences in geology could impact water chemistry through water-rock interactions (Lasaga 1984) and ultimately impact k. Additional work should focus on improving our understanding of the variables affecting k. Specifically, spatial variability in k due to changes in stream water chemistry should be investigated prior to applying the salt dilution methodology described in this paper into other areas.~~

~~4.4 Citizen scientist repeatability~~

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~~In this context, repeatability refers to the overall likelihood that the measurement method can be successfully repeated by citizen scientists. Along these lines, there were several practical observations in the field worth briefly discussing. While difficult to quantitatively evaluate, we offer the following qualitative observations regarding the selection of a preferred citizen science streamflow measurement method.~~

- ~~**Required training** - Float and salt dilution require similar amount of training, which from our experience we estimate to be roughly four hours, involving both classroom and field time. The amount of training is strongly dependent on~~

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~~the background of the volunteers. Bernoulli requires additional training for how to minimize vertical movement of the metal measurement plate.~~

- ~~**Cost of equipment** - All methods require a SmartPhone, measuring scale, and measuring tape. Additionally, salt dilution requires an inexpensive EC meter (e.g. $15 HoneForest Water Quality Tester), a graduated cylinder, and a bucket.~~
- ~~**Number of citizen scientists required** - Teams of at least two citizen scientists are recommended for all methods; teams of three were preferred in our experience.~~
- ~~**Data recording requirements** - For float and Bernoulli, depth, width, and velocity (including distance and time) data needs to be recorded at multiple locations. Salt dilution only requires some basic data entry and a video of the breakthrough curve.~~
- ~~**Complexity of procedure** - Float and Bernoulli require detailed transects of the stream. Bernoulli is extremely sensitive to vertical movements in the metal measurement plate. Bernoulli is always very difficult for low velocities.~~
- ~~**Enjoyability of measurement** - We found that citizen scientists generally enjoyed watching the salt dilution breakthrough curves and found them less repetitive than the tasks associated with float and Bernoulli methods. Bernoulli measurements can be frustrating when trying to keep the metal measurement plate from moving vertically, especially when there is a soft streambed.~~
- ~~**Safety** - Both float and Bernoulli measurements require citizen scientists to wade through the stream. At certain flow rates this clearly poses a safety risk, especially for people who cannot swim. A clear benefit of the salt dilution method is that everything but the simplified float estimate can be performed from the stream bank. Note that the results from the simplified float method are only used to determine the salt dosing. If the salt dosing doesn't provide a large enough change in EC to be clearly observed, the measurement can be repeated with a higher flow estimate and corresponding increase in tracer solution.~~

~~4.5 Uncertainty in reference flows~~

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~~Uncertainty in measurements of reference flow (i.e. actual flow) affected uncertainty in our evaluation of the three flow measurement methods. Based on an ISO discharge uncertainty calculation within the SonTek FlowTracker software, the uncertainties in flow ranged from 2.5 to 6.0 %, with a mean of 3.7 %. Based on the literature (Rantz 1982; Harmel 2006; Herschy 2014), these uncertainties in reference flows are towards the lower end of the expected range for field measurements of streamflow. Therefore, we do not think that any systematic biases or uncertainties in our data change the results of this paper.~~

~~4.6 Reynolds number~~

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~~Turbulent mixing of flow is an important aspect of salt dilution flow measurements. Reynolds number is typically used as a quantitative measure of turbulence in fluid flow. In addition to density and viscosity, fluid velocity and a characteristic length are required for calculating Reynolds number. Many of our measurements were performed in mountainous headwater~~

~~streams with high slopes. To collect the most accurate reference flow measurements, however, we selected the lowest gradient stretch of the stream. The cross sections used for reference flow measurements were typically in the widest and deepest reaches of the stream to ensure the most laminar flow lines for accurate velocity and area measurements. Using velocity and characteristic length data from these reference flow measurement locations to calculate Reynolds number would not have been representative of the actual average Reynolds number of the stream reaches used for the salt dilution measurements. This is because selected stream reaches for salt dilution included steep gradients with lots of mixing, which were often either entirely upstream or downstream of reference flow locations. Therefore, we did not include Reynolds number in the correlation analysis for salt dilution.~~

~~**4.7** Flow measurement methods not evaluated~~

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~~We initially considered including the slope area method (USBR 2001) based on the Manning's equation for evaluation. The concept was to use a long clear flexible tube of a known length (e.g. 20 m) to measure the slope of the water surface using the principle of a water level. The tube was completely submerged and filled with water. The upstream end of the tube remained submerged and the entrance was held perpendicular to flow to ensure that only the pressure head of the stream was sensed at the tube inlet. The tube was stretched out longitudinally along the stream reach, and the downstream end of the tube was exposed to the atmosphere. The difference in water levels inside the downstream end of the tube and the stream water level immediately outside of the tube was measured. This change in head was divided by the total length of the tube to determine the slope of the water surface.~~

~~Within the first few days of field work, we concluded that this method was not suitable for piloting at the types of sites we were investigating. Because we were particularly interested in high gradient headwater streams, the primary problem was finding a stretch of stream long enough that was flowing at normal depth, without backwater and drops in the water surface caused by sudden changes in channel geometry (both longitudinally and latitudinally). An additional challenge of this method is that uncertainty in flow measurements are linearly proportional to uncertainty in estimations of the roughness coefficient (n), and n is difficult to estimate visually, especially for citizen scientists. Therefore, Manning's method was not included in this investigation. Despite our experience, we suggest that in certain settings with long straight reaches of uniform flow, Manning's may still be an appropriate citizen science flow measurement method. To simplify observations of the change in head, the Manning's method would also benefit from the installation of upstream and downstream staff gauges survey to a common datum. However, this would make the method difficult and costly to implement, and therefore less scalable.~~

~~**4.8** CS Flow campaign~~

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~~The CS Flow Campaign provided us with a unique opportunity to evaluate the preferred salt dilution citizen science streamflow measurement method at a larger scale. In addition to the valuable streamflow data that will help us characterize~~

~~the hydrological situation in the Kathmandu Valley with greater precision, we also learned many practical lessons about how to apply citizen science based streamflow generation methods at a broader scale. Unfortunately, there was no systematic way to evaluate the accuracy of all the measurements performed. However, at the five locations were S4W-Nepal FlowTracker measurements were available, the resulting errors (μ = -6.7 %, std dev = 11.5 %; Table 2) where comparable to our initial evaluation data (μ = 8.2 %, std dev = 17.2 %; Table 1).~~

~~Linear regression forced through the origin between reference flows and salt dilution measurements had slopes of 0.90 and 1.01 with an r-squared values of 0.97 and 0.98 for CS Flow measurements and our initial evaluation measurements, respectively. Goodness of fit was similar, but while evaluation measurements had a slight positive bias (1 %), CS Flow measurements had a larger negative bias (-10 %). One possible explanation for this is that the three CS Flow comparisons that had negative percent differences (i.e. BM02, NA02, and BA01; Table 2) all used reference flows performed prior to CS Flow measurements. Since hydrographs during this season are gradually receding prior to the onset of the South Asian Monsoon, it is possible that the actual flow of the streams decreased between reference flow and CS Flow observations.~~

~~As flows decreased, we observed a progressively increasing positive bias between simplified float estimates and salt dilution measurements (Fig. 7). This finding is congruent with previous efforts to characterize the dynamic relationship between channel depth and surface velocity coefficients (USBR 2001; Escurra 2004). Average stream depths were often on the order of a few centimeters for the headwater catchments observed. Surface velocity coefficients provided by USBR (2001) range from 0.66 to 0.80 with increasing depths, but are held constant at 0.66 for depths less than 0.3 meters. Our results indicate that for flows less than 0.01 $m^3 s^{-1}$ a surface velocity coefficient of 0.5 would be more appropriate. The strength of the relationship between salt dilution and float streamflows also deteriorates as flows decrease (i.e. r-squared equals 0.83, 0.69, and 0.50 for plots 1, 2, and 3, respectively). This suggests that surface velocity coefficients are highly variable at low flow rates and correspondingly shallow depths.~~

5 Summary and future work

Of the simple streamflow measurement methods evaluated in this paper, salt dilution provides the most accurate streamflow measurements for both “experts” and citizen scientists alike. Our aims in this paper were to (1) perform an initial evaluation of these three potential simple streamflow measurement methods (Phase 1), (2) evaluate the same three methods with actual citizen scientists (Phase 2), and (3) apply the selected approach at a larger scale (Phase 3).~~Our aim in this paper was to (1) evaluate possible citizen science streamflow measurement methods, (2) select a preferred approach, and (3) pilot test the selected method in a real-world setting. We evaluated three different~~ In both Phases 1 and 2, salt dilution method resulted in the lowest absolute errors and biases (~~approaches (i.e. float, salt dilution, and Bernoulli run-up)~~Table 5) compared to float and Bernoulli methods.

Table 5: Summary of average absolute errors (Avg Abs Error), average biases (Avg Bias), and error standard deviations (Std Dev Error) for Phase 1 and 2 measurements. All values shown as percentages rounded to the nearest integer.

Phase	Performed by	Metric	Float Method	Salt Dilution Method	Bernoulli Method
1	Authors	Avg Abs Error (%)	23	15	37
		Avg Bias (Avg Error (%))	8	6	26
		Std Dev Error (%)	29	19	62
2	"Expert" (Authors)	Avg Abs Error (%)	41	21	43
		Avg Bias (Avg Error (%))	41	19	40
		Std Dev Error (%)	34	26	51
2	CS Flow Groups	Avg Abs Error (%)	63	28	131
		Avg Bias (Avg Error (%))	52	7	127
		Std Dev Error (%)	82	36	225

During Phase 1, we (the authors) performed 20 comparison measurements including float, salt dilution, and Bernoulli methods in headwater catchments of the Kathmandu Valley during March and April of 2017. For reference flows, we performed USGS mid-section method discharge measurements with a SonTek FlowTracker acoustic Doppler velocimeter (ADV). Reference flows ranged from 6.4 to 240 L s^{-1}. Absolute errors averaged 23, 15, and 37 %, biases were 8, 6, and 26 %, and error standard deviations were 29, 19, and 62 % for float, salt dilution, and Bernoulli methods, respectively.

During Phase 2, we partnered with 37 citizen scientists (second and third-year Bachelors' student volunteers from Khwopa College of Engineering) to evaluate the same three measurement methods in a citizen science flow (CS Flow) evaluation. In September 2018, CS Flow groups and an "expert" group (authors) performed measurements at 15 sites (seven in the Dhobi and eight in the Nakkhu watersheds). Reference flows, measured with a FlowTracker ADV, ranged from 4.2 to 896 L s^{-1}. "Expert" absolute errors averaged 41, 21, and 43 %, while for CS Flow groups they averaged 63, 28, and 131 % for float, salt dilution, and Bernoulli methods, respectively. While there was an increase in absolute error from the "expert" to the CS Flow groups (i.e. 21 to 28 %), salt dilution had the smallest incremental difference of the three methods. "Expert" biases averaged 41, 19, and 40 %, while for CS Flow groups they averaged 52, 7, and 127 % for float, salt dilution, and Bernoulli methods, respectively. Average bias for the salt dilution method was lower for CS Flow groups than for the "expert" (7 compared to 19 %), while for float and Bernoulli methods biases were higher. "Expert" error standard deviations were 34, 26, and 51 %, while for CS Flow groups they were 82, 36, and 225 % for float, salt dilution, and Bernoulli methods, respectively. Based on these results, we selected salt dilution as the preferred simple streamflow measurement method.

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Finally, during Phase 3, we performed larger scale pilot testing of the salt dilution method in week-long pre and post-monsoon (April and September 2018) CS Flow campaigns involving 25 and 37 citizen scientists, respectively. Observed flows (n = 131 pre-monsoon; n = 133 post-monsoon) were distributed among the 10 headwater catchments of the Kathmandu Valley and ranged from 0.4 to 425 L s^{-1} (pre) and 1.~~5~~1 to 1804 L s^{-1} (post). Histograms of flow and EC showed the increase in flows and the decrease in EC from pre to post-monsoon. The Department of Hydrology and Meteorology in Nepal operates three gauging stations in the Kathmandu Valley, so these additional data should add important spatial and temporal resolution to the distribution of streamflow in the Kathmandu Valley. During salt dilution measurements, background EC of streams and springs is also measured, which provides information about water quality.

~~by performing 20 side by side comparison measurements in headwater catchments of the Kathmandu Valley. We used USGS mid-section discharge measurements from a SonTek FlowTracker acoustic Doppler velocimeter as reference flows. Evaluated flows ranged from 0.006 to 0.240 m^3 s^{-1}. Linear regressions forced through the origin for scatter plots with reference flows had slopes of 1.05, 1.01, and 1.26 with r-squared values of 0.90, 0.98, and 0.61, for float, salt dilution, and Bernoulli run-up methods, respectively. The salt dilution method was selected as the preferred approach based on its favourable quantitative results compared to the other methods, and other qualitative factors concerning citizen science repeatability. The approach was then pilot tested in a CS Flow Campaign, which involved 20 volunteers performing 145 measurements, ranging from 0.0004 to 0.425 m^3 s^{-1}, distributed among the 10 headwater catchments of the Kathmandu Valley. While there was no way to evaluate the accuracy of all 145 measurements, five of the measurements were performed in locations where USGS mid-section method discharge measurements had been performed. For these five locations, a linear regression forced through the origin between reference flows and CS Flow measurements had a slope of 0.90 with an r-squared value of 0.97.~~

~~Motivated by these promising results, f~~Future work should further evaluate the feasibility of applying citizen science based salt dilution streamflow measurements to larger areas of Nepal and beyond. The information content of additional streamflow data should be explored. Issues of how to effectively recruit and motivate citizen scientists and young researchers (i.e. all science and engineering minded students from primary through graduate school ages) to participate in citizen science streamflow measurement efforts should receive additional attention, especially in the relatively unexplored context of citizen science in Asia. Finally, the assumption of a constant calibration coefficient (k) should be evaluated over a larger sample size covering a broader range of geological and water quality conditions.

6 Data availability

The data used in this paper are provided as supplementary material.

7 Author contribution

Jeffrey C. Davids had the initial idea for this investigation and designed the experiments in collaboration with Martine M. Rutten, Wessel David van Oyen, and Nick van de Giesen. Field work was performed by Jeffrey C. Davids, Anusha Pandey, Nischal Devkota, Wessel David van Oyen, and Rajaram Prajapati. Jeffrey C. Davids prepared the manuscript with valuable contributions from all co-authors.

8 Competing interests

The authors declare that they have no conflict of interest.

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~~This research was performed in the context of a larger citizen science project called SmartPhones4Water or S4W (Davids et al. 2017; Davids et al. 2018; www.SmartPhones4Water.org). S4W focuses on leveraging citizen science, mobile technology, and young researchers to improve lives by strengthening our understanding and management of water. S4W's first pilot project, S4W-Nepal, initially concentrated on the Kathmandu Valley, and is now expanding into other regions of the country and beyond. All of S4W's efforts, including the research herein, have a focus on simple field data collection methods that can be standardized and scaled so that young researchers and citizen scientists can help fill data gaps in other data scarce regions.~~

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