REACH Improving water security for the poor

Working Paper

Guideline: Selection, training and managing para-hydrologists

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Key words:

Community-based monitoring, citizen science, para-hydrologist, participatory approach, hydroclimatology, hydrometeorology, water security, water resources, water management, shallow groundwater, land degradation, rural communities, Ethiopia, India

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Project organisations:

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Purpose and scope:

This guideline is the second part of a two-part series concerning citizen science hydroclimate monitoring. The two guidelines were designed to be simultaneously consulted though the first is focused particularly on Ethiopia. The documents have been developed following citizen science research in Ethiopia since 2014 and in India since 2016 where multiple study sites have had community-based, or citizen science, monitoring (CBM) implemented using an iterative process leading to continual improvement of the methodology. In addition, the guidelines consider successful CBM in the UK and South Africa which have informed and been informed by the Ethiopia and India research.

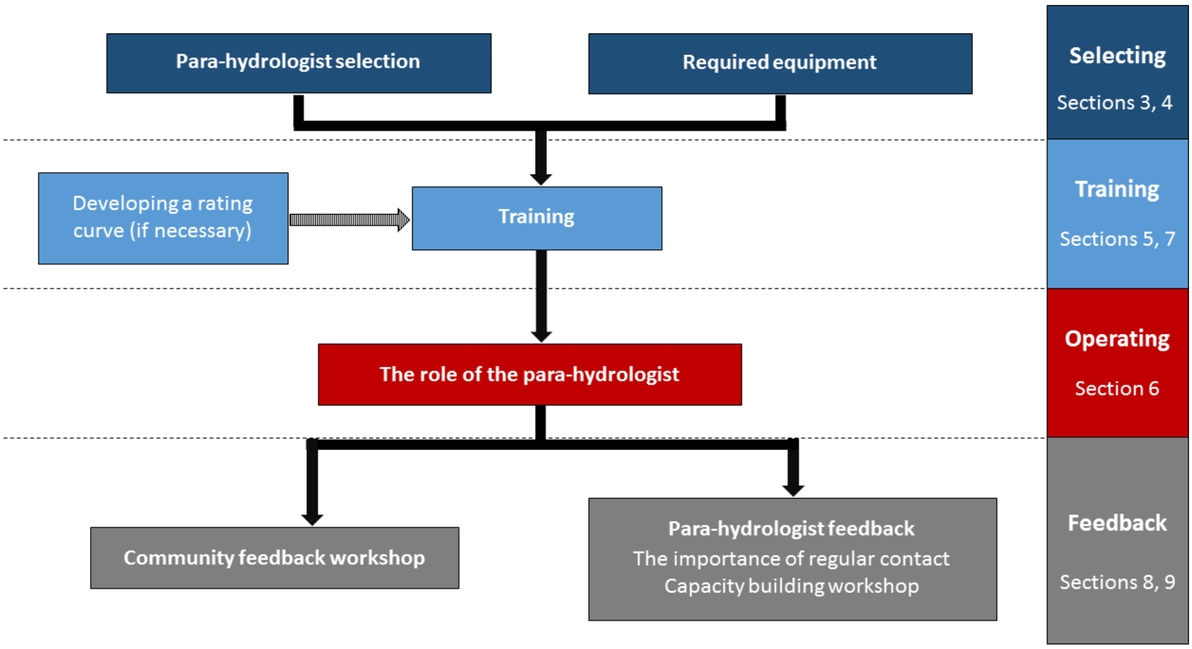
CBM is proposed as a solution to data scarcity in watersheds where a better understanding of water resources is required. CBM can provide continuous time series of hydroclimate data, which are invaluable in quantifying water fluxes and storage.

The first guideline of this two-part series detailed the planning, set up, and sustainable running of CBM. It is referred to throughout this document as the First CBM Guideline (Walker et al., 2019), which can be found at here. *The First CBM Guideline* recommends appointing a focal person, or "para-hydrologist" to act as an intermediary between the community and those who initiated the citizen science programme. This second guideline provides further detail on the role of the para-hydrologist, their selection and training, and the background of such "para-scientists".

The para-hydrologist's role is essentially to:

- Coordinate monitoring activities
- Provide guidance to the observers
- Collate, digitise and quality check the data
- Archive and forward the data
- Liaise with higher level stakeholders
- Disseminate findings to the local community

This second guideline is aimed at technical staff involved in introducing CBM such as researchers, development agents and district level experts. The purpose of the guideline is to give guidance on the selection, training and managing of para-hydrologists to ensure the successful running of CBM. Careful selection of a para-hydrologist is an important matter

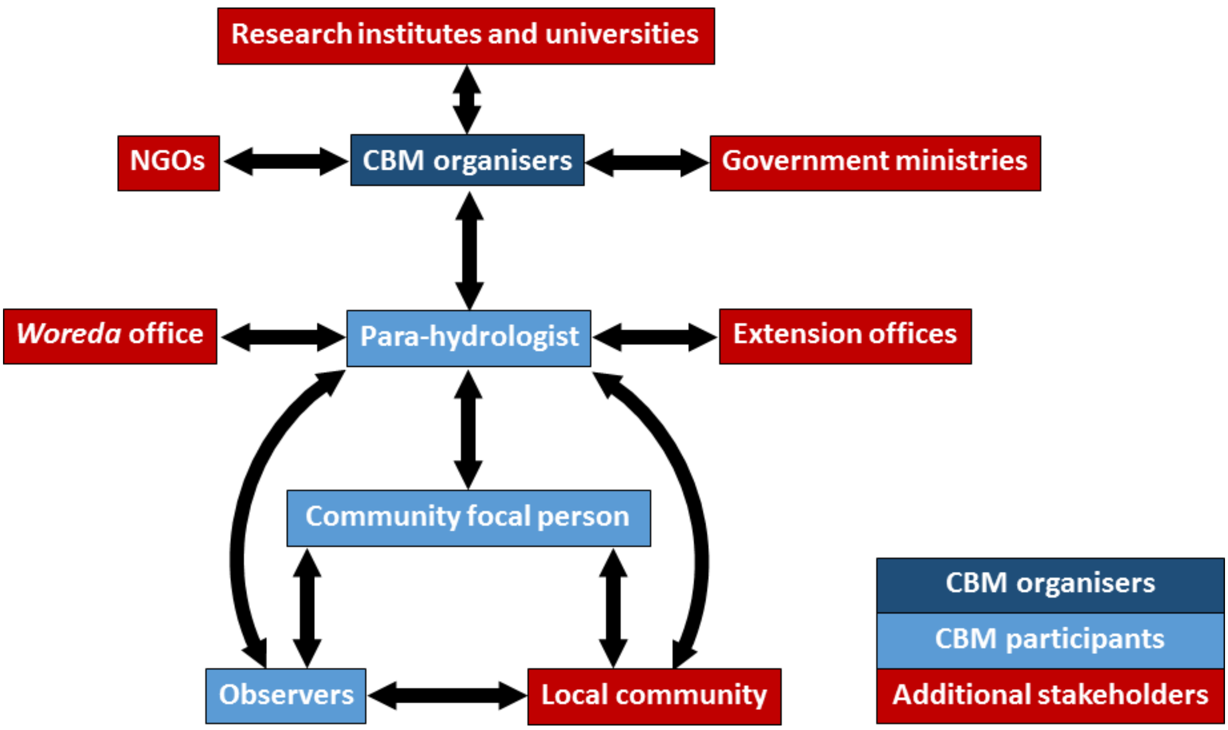


to ensure the effectiveness of the programme. The para-hydrologist will require greater training than observers who collect the data, and should ultimately be able to train observers themselves. The guideline gives step by step instruction on specific roles of the para-hydrologist, particularly development of a river stage-discharge relationship (a rating curve). It is noted that day to day hydroclimate monitoring is covered within the *First CBM Guideline* because making such measurements is principally the role of observers rather than a para-hydrologist.

A methodology flow diagram is presented on the previous page. The steps shown in the diagram conform to sections of this guideline.

An organisational chart is presented below showing the lines of communication for successful operation of CBM; note the para-hydrologist is in the centre of this diagram, illustrating their criticality. The arrows also represent the flow of data and of knowledge. It is noted that the "CBM organisers" at whom this guideline is aimed may be from the adjacent stakeholders within the organisational chart, i.e. research institutes, universities, NGOs or government ministries. Similarly, the para-hydrologist is likely to be from the *woreda* (district) office or an extension office.

Despite its preparation for the implementation of further CBM at sites in Ethiopia and India, the methodology presented in this guideline should be largely applicable anywhere in the world. Different governance structures and cultural variations may mean that stakeholders must be approached and community consultations run in a country-specific manner. However, the technical detail here presented is widely applicable.



Document history:

The requirement for this guideline was first expressed by the Ethiopian Ministry of Agriculture and Natural Resources (MoANR) during a hydrogeology and citizen science capacity building workshop in Addis Ababa run by Newcastle University and International Water Management Institute (IWMI) in May 2018. In the case of Ethiopia, the World Bank have stated that hydroclimate monitoring is required to ensure positive impacts of their funded watershed interventions that are managed by the MoANR. Additionally, implementation of citizen science, including para-hydrologists, is promoted to fill gaps in hydroclimate monitoring across the collaborator hubs in the Global Challenges Research Fund (GCRF) Water Security and Sustainable Development Hub. This United Kingdom Research and Innovation (UKRI) funded project is led by Newcastle University with collaborator hubs in India, Malaysia, Colombia and Ethiopia. The guideline was initially prepared by Newcastle University and IWMI based on experience of establishing and running multiple CBM programmes around Ethiopia, India, Kenya, South Africa and the UK. It was decided to produce two guidelines to maximise the utility and transferability of the research to date: *the First CBM Guideline* concerns planning, establishing and operating CBM and is specifically aimed at the Resilient Landscape and Livelihood Project (RLLP) in Ethiopia; this second guideline concerns selecting, managing and training para-hydrologists and has broader applicability. A two-day writing retreat was held in Bishoftu, Ethiopia, in October 2018 with participants from Newcastle University, IWMI, the MoANR Sustainable Land Management (SLM) programme, and the Water and Land Resource Centre (WLRC) at which the first guideline was co-produced. During the writing retreat, many prepared sections were improved and designated for transferral to this second guideline. A second three-day writing retreat was held in Bahir Dar, Ethiopia, in March 2019 with participants from Abay Basin Authority, Bahir Dar University, Hawassa University, Arba Minch University and two para-hydrologists from Dangila Agricultural Office and Boloso Bombe Agricultural Office respectively. The workshop was the first stage of a two-part review of this second guideline; the second stage being internal review at the School of Engineering, Newcastle University. Co-production of the guidelines drew on combined experiences with significant input from the institutions who would be in charge of implementation of CBM and para-hydrologists.

Contents:

Glossary:

Catchment	See "watershed".
Citizen science	Scientific work undertaken by members of the public, often in collaboration with or under the direction of scientific institutions.
Community-based monitoring (CBM)	Regular monitoring of meteorology and hydrology, e.g. rainfall, river stage and groundwater level, by members of the public.
Current-meter	A device with an impellor or electromagnetic sensor that measures water velocity, which is used for flow gauging.
Datalogger	An electronic device that stores automatic measurements until the data can be downloaded.
Dip-meter	A measuring tape with an electronic tip that beeps when in contact with water, which is used for measuring depth to the water level.
First CBM Guideline	The first guideline of this two-part series, which details planning, establishing and operating community-based hydroclimate monitoring (CBM). See https://reachwater.org.uk/resource/guideline-community-based-hydroclimate-monitoring-planning-establishing-and-operating/
Flow gauging	Measurement of water velocity and depth across a stream cross-section for calculation of discharge.
Formal hydroclimate monitoring	Regular monitoring of meteorology and hydrology, e.g. rainfall, river stage and groundwater level, by trained professionals working for national institutions.
Kebele	The smallest administrative unit in Ethiopia; equivalent to a village or parish.
Manual rain gauge	A rain gauge that stores water; the stored water volume is measured every 24 hours to give the daily rainfall total.
Observer	A person who makes measurements; a data collector.
Para-hydrologist	A community member who, although not formally (university) trained in physical sciences or engineering, has acquired sufficient basic understanding of hydrological principles and techniques, and is recognised within the community as a competent person. Her/his role is to function as an intermediary between the community and external agencies.

Pressure transducer	An electronic device that automatically measures water pressure, which can be converted to water depth.
Recharge	Water that infiltrates into the ground and contributes to groundwater storage.
River stage	The water level of a river above a local reference elevation, i.e. the riverbed.
Smartphone app	A computer program designed to run on a mobile phone.
Staff gauge	A graduated board placed into a river from which water level can be directly observed.
Tipping-bucket automatic rain gauge	An automatic rain gauge that accurately measures rainfall. Rainfall travels down a funnel and drips into a carefully calibrated 'bucket' balanced on a pivot. The bucket is held in place by a magnet until it has filled to the calibrated amount (approximately 0.02 mm of rain). When the bucket has filled to this amount, the magnet will release its hold, causing the bucket to tip. The water empties down a drainage hole and the bucket triggers a switch, sending a message to the datalogger.
Watershed	The area drained by a river system. Also known as a catchment.
Woreda	The second smallest administrative unit in Ethiopia; equivalent to a district.

List of abbreviations and acronyms:

ATA	Agricultural Transformation Agency
CBM	Community-based monitoring
GCRF	Global Challenges Research Fund
IWMI	International Water Management Institute
mbgl	Metres below ground level
MoANR	Ministry of Agriculture and Natural Resources
MoWIE	Ministry of Water, Irrigation and Electricity
NGO	Non-governmental organisation
NMA	National Meteorology Agency
PET	Potential evapotranspiration.
RLLP	Resilient Landscape and Livelihood Project
SLM	Sustainable Land Management
UKRI	United Kingdom Research and Innovation
WLRC	Water and Land Resource Centre

1. Introduction

Formal hydroclimate monitoring networks are sparse in many regions of the world. Rainfall and river discharge monitoring is in decline and groundwater monitoring is non-existent in many developing regions. Research has shown that high quality meteorological, hydrological and hydrogeological data can be collected by non-specialists from local communities (Figure 1) to complement that from formal sources or provide time series where no formal alternatives are available (Walker et al., 2016).

The participation of non-specialists in scientific data collection and subsequent data interpretation is known as "citizen science". In Europe and North America, there is a long tradition of non-specialists participating in scientific inquiry, especially wildlife surveys (Parkin, 2018). However, such surveys provide data "snapshots"; within the field of water resources, sustained time series are most useful. Time series of rainfall, river discharge, evapotranspiration and groundwater level allow us to understand watershed behaviour by quantifying fluxes and storage and analyse how they change with time. We can compute watershed water balances, estimate groundwater recharge, assess the impacts of climate variability and land use change on water resources, and run models to simulate future scenarios, among other applications. For potential applications of community-based hydroclimate monitoring, in addition to description of the hydrological cycle and the watershed hydrological balance, refer to the *First CBM Guideline* concerning planning, establishing and operating CBM (Walker et al., 2019).

(a)

(b)

(c)

FIGURE 1: A community-based hydroclimate monitoring programme in Ethiopia. (a): River staff gauge. (b): Raingauge. (c): Measuring groundwater level in a hand-dug well. Photos from: David Walker.

Our experience in Ethiopia and India has shown that careful selection of a suitable focal person, or "para-hydrologist" is key to the success and sustainability of CBM. However, guidelines to implement such programmes are noticeably absent. We, therefore, prepared this document to fill this gap which is partly hindering the promotion of citizen science for hydroclimate monitoring. While the *First CBM Guideline* detailed setting up and running CBM (Walker et al., 2019), this second guideline covers the role of the para-hydrologist, their selection and training, and the background of such "para-scientists".

The document was prepared using our experience of implementing citizen science in various watersheds in Ethiopia since 2014 and India since 2016, with consideration of further citizen science programmes we have been involved with in South Africa and the UK. Incorporated are inputs from national partners in Ethiopia including staff of MoANR (the Ministry of Agriculture and Natural Resources), MoWIE (the Ministry of Water, Irrigation and Electricity), WLRC (Water and Land Resource Centre), and various Ethiopian academic institutions.

2. Background

2.1. Learning from experiences with other 'barefoot scientists'

The concept of a 'barefoot scientist' originates in China with the introduction of 'barefoot doctors' in 1968 as an attempt by the Government to solve the basic health-care problems of rural areas (Zhang and Unschuld, 2008). During their short existence, until the 1980s due to a change in the system of rural area medical care, they provided effective medical services in rural areas and demonstrated the legitimacy of the concept of a 'barefoot scientist'.

The idea has been replicated in other contexts, such as 'para-vets' or community based animal health workers. These animal health delivery systems build upon the knowledge, participation, and needs of livestock-owning communities. They originated in the 1980s from new participatory approaches involving partnerships between development agents (often NGOs) and local communities (Catley et al., 2002). The role of 'para-ecologists' in planning and implementation of sustainable environmental management, where the primary focus is biodiversity conservation, is discussed by Schmiedel et al. (2016). They define a para-ecologist as "a resident professional with local knowledge who lacks formal academic training, being largely trained on-the-job, in one or more fields of ecological and taxonomic science". Their role is seen as contributing to scientific research and local capacity development and enhancing communication between local and scientific communities. They conclude that para-ecologists can play an important role in bridging the gap between science and local knowledge by building relationship between scientists and local communities. Bridging this same gap between science and local knowledge by building relationship between scientists and local communities is also the role of para-hydrologists.

2.2. Definition of a para-hydrologist

A para-hydrologist[1] is a community member who, although not formally (university) trained in the physical sciences or engineering, has acquired sufficient basic understanding of hydrological principles and techniques, and is recognised within the community as a competent person. The acquisition of basic hydrological understanding may not initially be present and could result from on the job training through their involvement in the citizen science programme. Her/his role is to function as an intermediary between the community and external agencies having a formal role in land and water resource governance. She/he will (i) coordinate community-based hydro-climate monitoring activities, (ii) communicate relevant scientific issues raised by external agencies to community members and local institutions, and (iii) relay community concerns to relevant external agencies.

1 Para-hydrologist may alternatively be known as a 'barefoot hydrologist'

If we consider readiness and capacity for collective management of land and water resources in the local community, it is possible to identify a "para-hydrologist shaped gap" in terms of the conditions needed for implementing participatory resource management. Experience suggests that:

- Community members may have some qualitative understanding of the temporal and spatial variability of the water resource, but they lack understanding of the hydrological processes which give rise to the perceived behaviour and therefore cannot manage them effectively.
- If resource monitoring and evaluation is conducted by "outsiders" (external agencies), community members may not trust their findings, and local institutions will not be enabled to use this knowledge to improve resource management.
- If resource monitoring and evaluation is conducted by the local community, external stakeholders may not recognise its legitimacy and may be reluctant to incorporate this information in decision making processes.

In summary, a para-hydrologist, by acting as a locally embedded community/project ambassador, could be a valuable asset for participatory resource monitoring and management through:

- Archiving, quality-checking, and communicating data gathered at community level to competent resource management agencies;
- Documenting with photographs and periodic reports any temporal changes to watershed characteristics;
- Translating local knowledge of environmental conditions into scientific terminology;
- Communicating scientific concepts (e.g. hydrological processes) in comprehensible terms and local language to community members;
- Relaying data and stakeholder concerns about water resources availability and priorities for infrastructure development to scientists and planners;
- Providing further teaching on hydrological monitoring methods for local community after initial training activities involving scientists/engineers;
- Supporting local resource management institutions through provision of data and information for evidence-based decision making.

2.3. Para-hydrologists in community based groundwater management in India

India's 12th five-year plan envisages extensive aquifer mapping leading to participatory strategies for groundwater management which are to be rolled out across 30% of the country where groundwater is under most stress. A position paper by the Central Groundwater Board (2012) recognised the important role of 'paraprofessionals' in this process. Thus para-hydrogeologists would provide technical backup to the participatory process through their base at district or block level. To provide the necessary coverage it is envisaged that around 20,000 para-hydrogeologists will be required. There is some documented evidence that substantial numbers have already been trained.

Tambe et al. (2013) reported an initiative in Sikkim (Himalayan foothills) which included developing a cadre of in-house trained para-hydrogeologists. Existing in-house staff at 'block' level were trained in hydrogeology and watershed management with the help of WWF-India and other NGOs. These staff operated as trainers and catalysts in supporting community based groundwater management with a particular focus on protecting and improving springs.

In Meghalaya State, where nearly all of the 6800 villages depend on springs and spring-fed rivers for household water needs, a large-scale community-based initiative was setup along similar lines to the experience in Sikkim. The goal of the Meghalaya Springs Protection Initiative (MINR, 2015) is to build awareness about the importance of springs and then build capacity to identify and protect springsheds – the areas where springs are being recharged. Para-hydrogeologists, who can map resources and participate as stake-holders are seen as the key to success.

3. Para-hydrologist selection

3.1. Selection criteria

Assuming that the initial sections of the *First CBM Guideline* have been followed concerning the purpose and planning of CBM, we are now at the stage of the initial site visit. The following should have already taken place:

- The study site has been selected
- The purpose of monitoring is defined
- Institutional stakeholders (e.g. district level government or agricultural extension offices) are engaged
- Planning has taken place in terms of what will be monitored and how, data management and archiving procedures, and what incentives will be provided to observers

The next step at the initial site visit is to identify a para-hydrologist. The importance of correctly selecting the para-hydrologist cannot be understated. The criteria are as follows:

1. **From the community** – The para-hydrologist need not live at the study site but experience has shown that they must be part of the local community. There is evidence that outsiders may not be as well received or trusted to the detriment of the project (Zemadim et al., 2014).
2. **Available** – The para-hydrologist's work and life commitments should not be such that they spend long periods away from the area. She/he should be a permanent resident of the district with a profession permanently based in the district. If the para-hydrologist is based nearby but not within the study site, as is common if they are a district level officer based in a town, ideally their normal work or life routines should cause them to visit the study site.
3. **Well known and respected** – It is wise to select a para-hydrologist that is known to the community through their work and who holds a respected position. For example, district level officers involved in agricultural outreach are likely to be known throughout the district in which they work.
4. **Responsible** – It is important that the para-hydrologist takes the role seriously and remains engaged in the programme.
5. **Literate and numerate** – Literacy and numeracy are important for all the observers, however, the para-hydrologist needs to conduct quality checking and some calculations rather than simply recording measurements. Therefore, a higher level of literacy and numeracy is required though training would be given where this is required, such as for developing stage-discharge relationships and applying weir equations (see later sections).
6. **Understands value of data** – Recognition of the value of reliable and accurate data is important. Additionally, quality checking, analysis and interpretation of data requires scientific thinking.
7. **Computer literate** – The para-hydrologist must be comfortable in typing up data onto Microsoft Excel or Google Docs, uploading photographs, emailing data, printing data sheets, and possibly plotting and analysing data using Microsoft Excel or Google Docs. Training would be given for these elements.
8. **Communication skills** – The para-hydrologist must be a good communicator, both to receive instructions and ask questions during training, and to train observers and disseminate findings to the community. Therefore, the observer must be proficient in the local language and the language of the organisers of the monitoring programme.
9. **Balance between women, men, youth and less able** – Considering all of the observers and the para-hydrologist, aim to achieve a balance between women and men. Citizen science programmes can be

considered an exercise in both promoting gender equality and empowerment of local communities giving them access to knowledge often held only by higher level stakeholders. Within communities a citizen science programme is an opportunity to empower women and less able people, and to encourage the youth.

10. **Willingness** – Lastly, though extremely important, the identified person must be willing and enthusiastic to give their time to fulfil the role as para-hydrologist.

The list above can be considered a checklist for selecting a para-hydrologist. There is overlap between many of the criteria; for example, a trait such as responsibility is likely to be a reason why the person is respected by the community, while literacy, numeracy and computer literacy may be a requirement of a person employed in their position.

While observers will generally be identified by the local communities themselves and by the para-hydrologist, higher level stakeholders should be approached to suggest a para-hydrologist. Regional officers from government ministries, agencies or institutions, as well as researchers and NGOs who have conducted work in the area, may all be able to suggest potential para-hydrologists. Senior personnel from local and district level stakeholder organisations, such as water user committees, agricultural research or outreach organisations and district councils, should be able to confirm or suggest a potential para-hydrologist, who would likely be from one of these organisations. Therefore, it is a requirement to seek the permission of the senior person before approaching the potential para-hydrologist.

Examples of para-hydrologists from successful CBM programmes in Ethiopia and India include:

- A district level irrigation officer based in the district's main town but known to the village communities due to their outreach work
- A district level natural resource officer who is also a village level contact person for community based watershed management activities
- Community outreach specialists from a local NGO.

3.2. Ethics

Research ethics considers the overall harms and benefits of research, the rights of participants to information and the responsibilities of researchers to act with integrity (CSJCA, 2012). There are various ethical questions in the field of citizen science and hydroclimatology that must be considered by the CBM organisers, especially when selecting para-hydrologists. Important ethical principles include:

- Informed consent – the CBM organisers should provide sufficient information on the project, i.e. the purpose and use of the data, the time frame, the duties, responsibilities and incentives, to enable the community members to decide on whether they want to be involved and to what degree.
- Equality and inclusion – citizen science is an opportunity to actively include and encourage involvement of people from groups that are often excluded and to challenge discriminatory attitudes.
- Expectations – the CBM organisers should be clear to the community and to the para-hydrologist about the likely project outcomes at the onset of the project, i.e. promises should not be made that are unlikely to be fulfilled.
- Mutual benefits – it is essential that the CBM organisers *and* the citizen scientists *and* the host community benefit from taking part in the project.
- Compensation/incentives – consider how much time and effort the para-hydrologist is expending on the project and whether they should rightly be compensated.
- Capacity building – the para-hydrologist and the observers may, if they wish, be allowed to participate in multiple stages of the scientific process.
- Feedback – the para-hydrologist and the community involved in CBM should receive feedback on the project.

- Mutual respect – the CBM organisers must be prepared to listen to and acknowledge the diverse opinions of community members and para-hydrologists.

3.3. Gender

Women often play a leading role in obtaining and safeguarding water, but this role is generally not reflected in institutional water management (Nigussie et al., 2018). Participation in CBM, especially as a para-hydrologist, could help to address gender inequality in water resource management. Giving women the opportunity to learn and share information concerning hydroclimatology can lead to empowerment and participation in decision-making from which they may previously have been excluded. Potential barriers to be aware of include reluctance of men to allow women in their households to participate in CBM, additionally, the CBM organisers should be careful not to add yet another unpaid time-consuming responsibility to already busy women. A gender-sensitive approach is required by the CBM organisers that will be specific to the country and culture of the study site and may require partnership with local organisations working for women's empowerment.

4. Required equipment

The equipment required for CBM is detailed in the *First CBM Guideline*. Additional equipment specifically required for a para-hydrologist can be considered optional and depends on what is being monitored and the available funding:

- Current-meter: If river stage is monitored then the observations need to be converted to river discharge. Flow gauging should be conducted by the para-hydrologist throughout the year when the water in the river is at different levels. A current-meter measures a river's velocity utilising an impellor (Figure 2) or electromagnetic probe. Current-meters vary in cost, the more expensive versions being more robust, more accurate and more user-friendly. If multiple study sites are not too distant from each other, it may be possible to share a current-meter between sites because they generally need to be used infrequently.
- Laptop or tablet computer: Typing up the handwritten data onto Microsoft Excel or Google Docs could be done at the para-hydrologists place of work or home if they have access to a computer. Provision of a laptop or tablet computer, therefore, may not be necessary. However, as a gesture of

FIGURE 2: An impellor current-meter in use for flow gauging in Ethiopia. Photo from: David Walker.

goodwill if the programme is proceeding successfully, provision of a computer should be considered. This will allow the data to be typed up and analysed at any time in any location. Laptops and tablets can these days be purchased relatively inexpensively.

5. Training

Given that, by definition, the para-hydrologist will have minimal formal training in hydroclimatology, initial training is required to build their existing knowledge. Training should be provided on basic hydrological processes in the context of their study site. To maximise the capacity building aspect of para-hydrologist training, the para-hydrologist should be involved at all stages of monitoring site selection, equipment demonstration to the community, equipment installation and observer training; the para-hydrologist should facilitate these procedures. Therefore, the para-hydrologist should receive specific instruction on:

1. Community consultation
2. Monitoring site selection
3. Observer selection
4. Monitoring equipment installation and maintenance
5. Observer training
6. Understanding and quality checking data forms

Guidance on points 1 to 6 above is provided in the *First CBM Guideline*. Additionally, the para-hydrologist could contribute to the collection of invariant data for study site characterisation. Such data may include land use and land cover types, soil types, vegetation, and identification of areas of the study site with specific vulnerabilities. In these cases, additional training would be necessary. Further instruction is required, ideally while sitting together at a computer, which may be the newly provided laptop or tablet, concerning:

7. Printing data forms for the observers
8. Typing up the data – Common errors and typos should be demonstrated.
9. Adding comments to the data – The para-hydrologist should be encouraged to supply comments on the CBM, such as the state of the equipment, changes at the monitoring sites, extreme hydrometeorological events or anything else deemed pertinent (Figure 3).
10. Uploading photographs – To support the comments, photographs can be uploaded.
11. Combining the data – Converting monthly datasets into continuous time series enables plotting.
12. Plotting and interpreting data – The para-hydrologist should be shown how to create simple plots of the monitoring data on Microsoft Excel or Google Docs (Figure 3). They should be taught to look for relationships between datasets and to notice any trends.

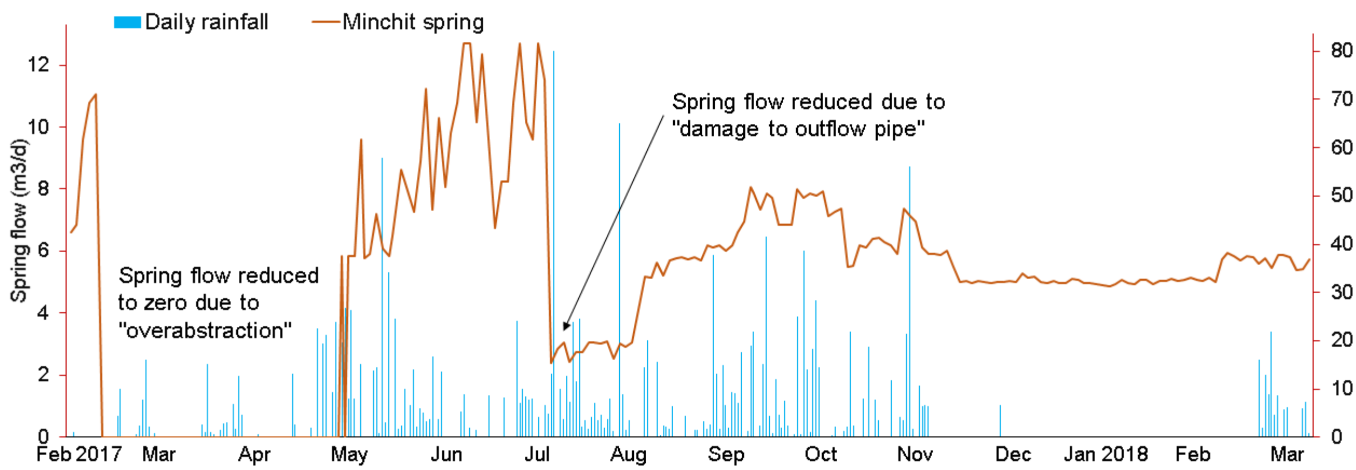


FIGURE 3: Plotted daily spring discharge and rainfall from a study in Ethiopia. Note the comments provided by the para-hydrologist explaining significant fluctuations in the data.

13. Emailing the data – If necessary, the para-hydrologist can be shown how to attach the data to an email for sending to the programme organisers. At this stage, the necessary email addresses should be provided.

Additional training may be required in the field and on a computer for the following, depending on what is being monitored:

14. Rainfall measurement
15. Groundwater level measurement
16. Spring discharge measurement
17. Flow gauging
18. Development of a rating curve
19. Use of a discharge app.

See the *First CBM Guideline* for instructions on points 14-16 and Section 7 of this document for instruction on points 17-19. In general, it is important that the para-hydrologist understands the value of reliable and accurate data. The purpose of the monitoring will be different at each study site and it should be clear to the para-hydrologist how the CBM data can contribute to fulfilling this purpose.

6. Duties of the para-hydrologist

The para-hydrologist's duties should not consume a large amount of time – this is important to maintain the interest of the selected person. The duties of the para-hydrologist are:

Monthly

1. Print and provide data forms to the observers – These can be provided in the form of a booklet (multiple monthly data forms stapled together) because we recommend that the observers always have at least three months' supply of data forms to negate printing or transportation issues.
2. Collection of data forms
3. Assessment of monitoring equipment – Conducted through conversation and observation with the observer when providing and collecting data forms. In the wet season, if there is chance of damage to the monitoring equipment, this assessment should be conducted more frequently, perhaps weekly. Any necessary cleaning and simple maintenance should be conducted immediately (Figure 4). In this case, the observer should

(a) (b)

FIGURE 4: Minor maintenance of monitoring equipment in Ethiopia. (a): Cleaning a raingauge and removal of tall obscuring grass. (b): Clearing debris (a tree branch) from a river staff gauge. Photos from: David Walker.

be reminded or trained by the para-hydrologist to conduct the cleaning and minor maintenance themselves.

4. Typing up, quality checking, and emailing the data – Additional comments and photos should be added at this stage.

Periodically

1. Substantial maintenance (if necessary) – Conducted if a monitoring site suffers damage, for example, if a river staff gauge or weir is damaged by debris, or if a raingauge is knocked over (Figure 5). Even though the para-hydrologist should be encouraged to make decisions autonomously, contact should be made with the organisers of the CBM in these cases, especially if the maintenance involves some cost. In the case of damaged equipment or changes at a monitoring site, adding photographs to the emailed data forms is invaluable.
2. Flow gauging (if necessary) – Conducted when the river stage is at different levels in order to develop a rating curve to convert river stage to discharge (see following section).
3. Combining and plotting the data – Any unexpected values in the data, often easily visible when plotted, should be investigated by the para-hydrologist. Such data may reveal equipment or observer issues requiring maintenance or some re-training, respectively. Comments and photographs can be added detailing the para-hydrologists findings.
4. Data interpretation – This is a two-way process where any relationships and trends in the data are shared between the para-hydrologist and the organisers of the CBM who should also be quality checking and analysing the data.
5. Share findings with the community – This can be done conversationally to assess if trends and relationships match anecdotal observations, e.g. seasonal shifts in rainfall onset and cessation that may be affecting crop sowing and harvest.
6. Relay important findings to higher level stakeholders – Any meetings or visits with institutions, agencies and organisations are an opportunity to provide data to support evidence-based decision making. Stakeholder concerns can be backed up with monitoring data. This could enable development of resource management strategies and of priorities for infrastructure development.
7. Attendance of para-hydrologist workshops (see Section 7).
8. Organisation and delivery of community feedback workshops (see Section 8).

(a) (b)

FIGURE 5: Substantial maintenance of monitoring equipment in Ethiopia. (a): Repairing the base and fence of a raingauge. (b): A river staff gauge requiring reconstruction following damage by floating debris during a flood. Photos from: David Walker and Dawit Bunduro.

7. Developing a rating curve

A rating curve, also known as a stage-discharge relationship, is the method of converting water level (river stage) to flow (river discharge). River stage must be converted to river discharge in order to quantitatively understand a watershed's water resources. This step would generally be conducted by the para-hydrologist or by the CBM organisers. This section is not incorporated within the training section because it is not a necessary step at study sites that do not involve river stage monitoring (and because, as stated, development of a rating curve may be conducted by the CBM organisers themselves). If river monitoring consists of stage measurements from a staff gauge or measuring from a bank top reference point then the time series of stage measurements should be converted to discharge by developing a rating curve. If a weir or flume is present, the time series of river stage above the base of the weir/flume can be converted to discharge using equations.

7.1. Flow gauging

The recommended method of generating a stage-discharge relationship, or rating curve, is to conduct velocity measurements at various times throughout the year when the river is at various levels. Velocity measurements are conducted using a current-meter at measured points across a river channel while also measuring river depth; a process known as "flow gauging" (Figures 6 and 7).

Training should involve demonstration at the monitoring site and the para-hydrologist should be taken to other reaches of the river where the stage is at different levels to test that they can correctly take measurements. It is important to explain how the equipment functions and how to change batteries.

Required:

- Two people: It is preferable for at least two people to conduct flow gauging for safety and for ease of recording the measurements
- Current-meter: Before visiting the flow gauging site, test that the current-meter is working correctly and the batteries are not in need of replacing
- Notebook and pen for recording measurements
- Measuring tape longer than the river width
- Consider safety equipment such as rubber boots or waders, a life jacket, and a safety rope

(a)

(b)

FIGURE 6: Flow gauging in Ethiopia with river stage at ~0.8 m (a) and at ~0.4 m (b). Photos from: David Walker.

Measurement procedure:

1. The river stage and/or flow should not be so high that entering the river would be hazardous.
2. The gauging site should be chosen on the basis of the following criteria:
    - The reach of river should be selected as close as possible to the stage measuring location.
    - If the flow gauging site is downstream of the stage measuring location, there should be no tributaries or other inflows into the river between the flow gauging site and the stage measuring site.
    - The reach should be straight.
    - Flow direction should be parallel with the channel sides along the reach, with no eddies or zones of 'dead' water.
    - The channel should be clear and unobstructed by trees, aquatic growth or other obstacles.
3. One person who is familiar with the current-meter, i.e. the para-hydrologist, should carefully enter the river.
4. The second person remains on the river bank with a notebook to record the measurements.
5. String a measuring tape tightly across the river, securing either end to the banks.
6. The edge of the river (point of zero water depth) should be located on the measuring tape strung across the river and the measurement (horizontal distance) should be spoken to and recorded by the second person.
7. Depending on the width of the river, velocity and depth measurements should be taken at intervals of 0.2-1.0 m. Aim for at least eight measurements across the channel, though this could be reduced when low flows reduce channel width to around 1-metre.
8. At each measuring interval, first the horizontal distance on the measuring tape is recorded.

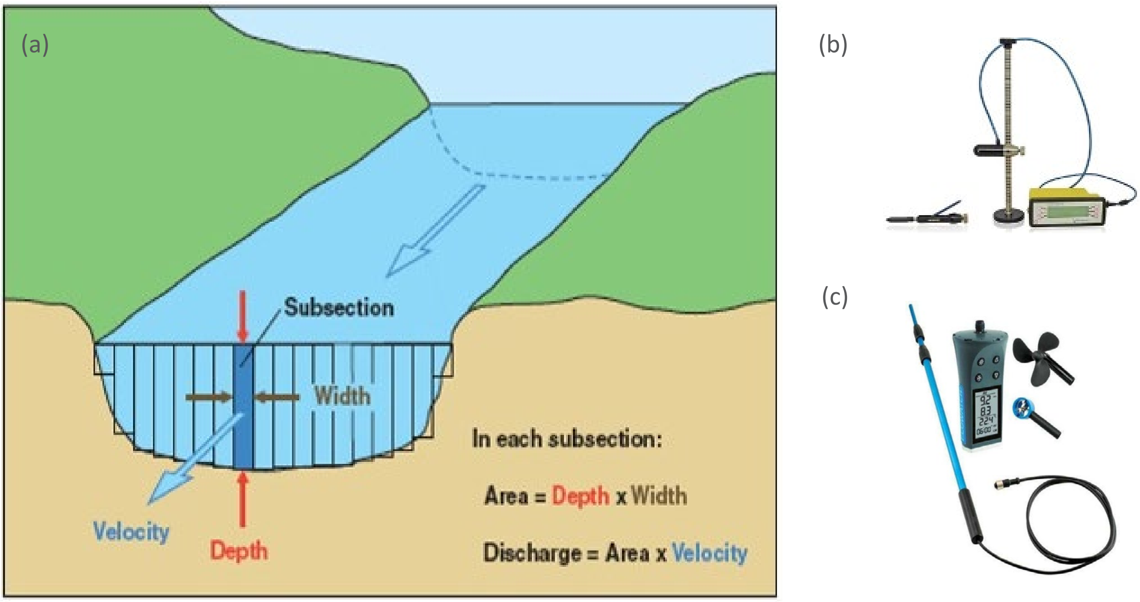


FIGURE 7: (a): Calculating discharge by measuring the velocity and area of each subsection of a channel cross-section to obtain discharge and then summing the subsection discharges to obtain total river discharge. (b): Electromagnetic current-meter. (c): Impellor current-meter.

Diagram from: https://water.usgs.gov/edu/streamflow2.html.

9. Second, the water depth is measured and recorded; current-meters typically incorporate a graduated staff for depth measurement.
10. Third, the impellor or electromagnetic probe should be placed at 0.6 x water depth for velocity measurement. The average velocity over 30 seconds is recorded; this averaging is usually conducted by the current-meter.
11. As with the near bank, the far bank should be recorded as the point of zero depth; together these horizontal measurements give the river width.

Caution:

- Flow gauging must be conducted safely. If high river flow prevents safe access to the measurement location, no attempt should be made to take a measurement. Similarly, extreme care must be taken where the riverbed is uneven.

Calculation procedure:

1. The "mean-section method" is used to calculate discharge for each subsection (Figure 7a) using:

$$Q_{sub} = 0.5\,(v1+v2)\ \times 0.5\,(d1+d2)\ \times b$$

[Equation 1]

where Q_{sub} is the discharge for each channel subsection (in m^3/s also known as cumecs), *v*1 and *v*2 are the average water velocities at vertical 1 and 2 respectively (either side of the segment), *d*1 and *d*2 are the depths of the flow at verticals 1 and 2 respectively, and *b* is the chosen width of each channel subsection.

2. The average velocity of the water in the two "end subsections" (adjacent to the river banks) are calculated by assuming zero depth and zero velocity at the water's edge (Dingman, 2015).
3. Following multiple flow gauging sessions with varying river stage, river stage is plotted against discharge (Figure 8).
4. A line of best fit is drawn through the points; the line can be extrapolated to incorporate river stage below and above the stage at the time of flow gauging (Figure 8b).
5. This line of best fit is the stage-discharge relationship, or rating curve. The equation of this line can easily be applied to all stage measurements on a Microsoft Excel or Google Docs spreadsheet to calculate discharge

(a)

Stage (m)	Discharge (m^3/s)
0.44	0.61
0.75	1.12
0.50	0.73
0.49	0.69
0.72	1.08
0.32	0.42
1.66	2.37

(b)

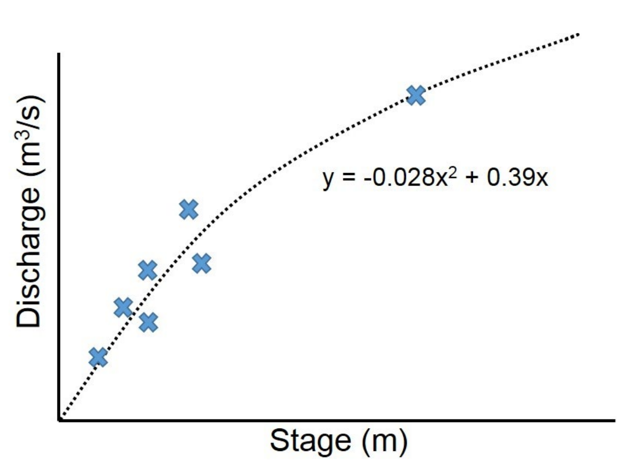


FIGURE 8: Development of a rating curve / stage-discharge relationship. (a): Calculated discharge at various river stages. (b): Plotted stage and discharge with a line of best fit and stage-discharge relationship which is the equation of the line.

7.2. Float method

Where a current meter is not available the flow may be estimated using the float method. The velocity of flow is estimated by releasing a float at different locations across a river and timing the travel between two measured points. The best floats are small heavy rounded objects that float when partially submerged; they are less affected by wind and are not slowed by striking the side of the channel. Objects that make good floats include: a long necked bottle partly filled with water and capped, a rounded block of wood, or an orange. Measurements are made of the width and depth of the channel to calculate the cross section area of flow. This method must also be applied with the river at varying depths in order to develop a stage-discharge relationship.

Required:

- Two people: It is preferable for at least two people to be present for safety and for ease of recording the measurements
- Measuring tape (approximately 15 m)
- Steel tape measure or graduated rod (at least 1 m)
- Float(s) – see paragraph above for recommended floats
- Stopwatch (or mobile phone)
- Notebook and pen for recording measurements
- Consider safety equipment such as rubber boots or waders, a life jacket, a safety rope

Measurement procedure:

1. The river stage and/or flow should not be so high that entering the river would be hazardous.
2. The gauging site should be chosen on the basis of the following criteria (Figure 9a):
    - The 5-15 m reach should be straight.
    - Channel width should be relatively uniform along the reach.
    - Channel cross section shape should be relatively uniform along the reach.
    - Flow direction should be parallel with the channel sides along the reach, with no eddies or zones of 'dead' water.
    - The channel should be clear and unobstructed by trees, aquatic growth or other obstacles (Figure 9b).
3. Identify the location of two or three cross sections (upstream, middle and downstream) which define the reach.
4. One person should carefully enter the river while the second person remains on the river bank with a notebook to record the measurements.

(a)

(b)

FIGURE 9: Potential flow gauging locations adjacent to staff gauges in Ethiopia. (a): A suitable straight reach conforming to the selection criteria. (b): A straight reach of river that would be unsuitable for float method flow gauging due to the obstructions within the channel. Photos from: David Walker.

5. Measure the length of the reach between the upstream and downstream cross sections. The length of the reach should be a minimum of 5 metres and may be up to 10-15 metres or longer if channel conditions allow.
6. Measure the stream cross section area at each cross section at the upstream, middle and downstream ends of the reach. The cross section area (A) is measured by measuring and recording the width of the water surface with a measuring tape and multiplying the width by the mean depth. The mean depth is measured by making a number of measurements of the depth at regular intervals across the channel using a steel tape or graduated rod and calculating an average depth.
7. Measure the velocity of the water by releasing a float at the upstream cross section and measuring the travel time it takes to arrive at the downstream cross section with a stopwatch.
8. Repeat the measurement several times, releasing the float at different locations spaced at regular intervals across the channel. In each case record the travel time taken by the float to arrive at the downstream cross section with a stopwatch.

Caution:

- As with flow gauging using a current meter, the float method must be conducted safely. If high river flow prevents safe access to the measurement location, no attempt should be made to take a measurement. Similarly, extreme care must be taken where the riverbed is uneven.

Caution procedure:

1. Calculate an average water velocity by dividing the length of the reach by the average travel time.
2. Note that this value is an average velocity for the water at the surface at the stream. Velocity decreases with depth to the stream bed. Therefore an average stream velocity (V) should be computed by multiplying the average surface velocity by a velocity coefficient. A velocity coefficient of 0.65 is suggested for shallow streams with average water depth of around 0.25 m; use 0.67 for water depths of 0.5 m; 0.7 for 1 m; 0.73 for 1.5 m, and; 0.76 for 2 m (Herschy, 2014).
3. Note that the velocity coefficient may be computed by measuring actual average stream velocity with a current-meter and dividing this by the surface velocity measured with the float.
4. Then use the velocity-area method to calculate discharge. Multiply the average stream velocity (V) by the cross section area of flow (A) to compute the discharge (Q):

$$Q = V \times A$$

[Equation 2]

5. Following multiple float method flow gauging sessions with varying river stage, river stage is plotted against discharge (Figure 8).
6. A line of best fit is drawn through the points; the line can be extrapolated to incorporate river stage below and above the stage at the time of flow gauging (Figure 8b).
7. This line of best fit is the stage-discharge relationship, or rating curve. The equation of this line can easily be applied to all stage measurements on a Microsoft Excel or Google Docs spreadsheet to calculate discharge.

7.3. Weir and flume equations

Weirs and flumes are constructed within water channels in order to enable calculation of flow (Figure 10). Weir/flume equations are applied, like a river rating curve or stage-discharge relationship, to convert measured stage in a weir or flume to discharge. The time series of stage measurements above the base of the weir/flume can be converted into discharge by applying an equation that describe this relationship. Each type of weir or flume has a unique equation to convert stage to discharge. A v-notch and/or rectangular weir are the most likely types of weir to be installed in a small river for a citizen science programme (Figure 10a). The equation to determine discharge through a v-notch weir is (Brater and King, 1976):

$$Q = 1.38 \tan(\vartheta/2)\, H^{2.5}$$

[Equation 3]

Where Q is discharge in m^3/s, θ is the angle of the v-notch in degrees, and H is the river stage above the base of the notch (or nap, or crotch) of the weir in metres.

The equation to determine discharge through a rectangular weir is (Te Chow, 1959):

$$Q = (L - 0.2H)H^{1.5}\,(1.805 + 0.221\, H/H_c)$$

[Equation 4]

Where Q is discharge (m^3/s), L is the horizontal weir length (m), H is the river stage above the weir crest (m), and H_c is the height of the weir crest above the channel bottom (m).

These equations can easily be applied to all stage measurements on a Microsoft Excel or Google Docs spreadsheet to give a discharge time series.

A flume is a structure similar to a weir that can be installed within an artificial channel (Figure 10b). Our research in Uttarakhand, India, involves monitoring of small (30-40 mm width) pre-fabricated metal flumes installed in channels above developed springs. As with weirs, flumes have an equation specific to their geometry to convert stage to discharge that will be supplied in the manufacturer's specification.

7.4. Smartphone apps

Smartphone apps (an application – a computer program installed on a smartphone) for measuring discharge are a recent development and are still unproven in natural river systems. A monitoring site must be setup with markers on the banks and the profile must be surveyed. The observer lines up the markers on the app, which is installed on a smartphone or tablet computer (Figure 11). The app analyses a video of the water surface, applying 3D particle tracking velocimetry (3D-PTV) to estimate the flow velocity, which it then converts to discharge (see Lüthi et al. (2014)). The advantages of such apps are that it is a very fast method of obtaining discharge that does not require entering the river (other

(a) (b)

FIGURE 10: A weir and a flume for monitoring flow. (a): A combined v-notch (for low flows) and rectangular weir (for higher flows) in South Africa. (b): A 30 mm flume within a stone-lined channel above a spring in India; flow is from top to bottom of the photograph. Photos from: David Walker.

FIGURE 11: Using a discharge app on a smartphone in Tanzania. Photo from: http://www.photrack.ch.

than obtaining the riverbed profile); it is therefore very safe and can be utilised in high flow conditions. However, research is ongoing and preliminary testing at Newcastle University suggests the technique can give inconsistent results depending on weather conditions such as wind strength and direction, sunlight angle, cloud cover, and the position of the observer in terms of their height and angle of the smartphone to the river. In the future, such apps may become the recommended method for rating curve development or may negate the need to take stage measurements at all.

8. Para-hydrologist feedback

8.1. The importance of regualr contact

Receipt of data from the para-hydrologist should be acknowledged. This acknowledgement email should also consider and potentially respond to any additional comments and photographs provided by the para-hydrologist. Any data quality issues identified by the receivers of the data should be relayed as soon as possible to the para-hydrologist for possible investigation to enable prompt resolution. It is recommended to highly appreciate the para-hydrologists when high quality data and photographs are collected. Analyses and interpretations of the data should also be shared with the para-hydrologist for their own education and so they may disseminate these findings to other stakeholders. When a para-hydrologist does not experience regular email or telephone contact, data quality can suffer. Thus, the para-hydrologist should be able to contact the research team, and get a response, at any time via email and telephone.

We recommend a study site visit at least twice per year, preferably more. Experience has shown that when a community and a para-hydrologist involved in a citizen science programme do not experience periodic face-to-face contact, data quality can suffer. During the site visit, a brief meeting should be organised involving both observers and para-hydrologists. Such a meeting helps to exchange experience and discuss how to deal with challenges.

8.2.Para-hydrologist capacity building workshop

It is recommended to hold an annual workshop for the benefit of para-hydrologists. Bringing para-hydrologists together from multiple study sites is an opportunity for capacity building and for them to discuss their work and learn from each other. It is also a gesture of goodwill towards the para-hydrologists and lets them know their participation in the citizen science programme is valued. Training on specific topics and techniques pertinent to the study sites should be given; bearing in mind it may be necessary to have translation into local languages. A single day is the minimum length for the event with at least half a day for presentations and at least half a day for group tasks. The location could be a university, hotel, office, anywhere with a room of sufficient size with the capability to project PowerPoint presentations. Therefore, funds must be available for room hire, travel and accommodation costs for the para-hydrologists, refreshments and stationery during the workshop, and possibly per diem payments for the participants in accordance with local customs. Feedback from para-hydrologist participants has typically indicated that once per year is the desired frequency.

The day could start with each para-hydrologist introducing themselves and providing information on their watershed. This should be facilitated by the workshop organisers who should prepare one slide per study site with photographs and plotted data. The information provided by each para-hydrologist for their study site could cover:

- Background: Location, geography and climate
- The CBM programme: What is the purpose of the monitoring, what is monitored, how is it monitored, monitoring frequency
- Problems faced at their site
- Findings from the monitoring
- Watershed management activities

The following capacity building sessions are suggested, some of which were requested by para-hydrologists on feedback forms. These sessions could involve presentations and group tasks:

- Understanding hydrogeology
- Catchment/watershed water balances
- The data quality control process
- Flow gauging and developing a rating curve
- Impacts of land degradation and interventions on water resources
- Data analysis on a computer

FIGURE 12: Group discussion task at a para-hydrologist capacity building workshop at Arba Minch University in Ethiopia. Photo from: David Walker.

- Potential impacts of climate change on water resources

Group discussion tasks can be conducted in the local language and everyone should be encouraged to participate (Figure 12). Breaking up into smaller groups would help if certain people are dominating discussions (put them in the same group). Suggested group discussion tasks are:

- Shared problems between study sites and suggested solutions – "What issues have you all experienced at your study sites? Think about equipment, data, working with the community and anything else. Together suggest and develop solutions to these issues."
- Positives at each study site and how they can be applied at all sites – "What do you all think is going well at your study sites? What have you all learnt about your study sites since the monitoring programme started? Suggest how these positives can be applied at all sites."
- Working with the wider community – "How should we consider:
    1. Community feedback and data visualisation
    2. Recognition of observers and community
    3. Managing community expectations
    4. Sharing knowledge across districts and regions
    5. Capacity building
    6. Anything else?"
- Plan an exit strategy – "The period of research, support and funding from the CBM organisers will likely come to an end at some point. How will the monitoring be continued? What support or training is required before that point?"

Notes should be taken on the discussions and disseminated to all participants, along with all presentations, following the event. The notes will be extremely useful when planning and initiating further CBM and for improvement of ongoing programmes. The para-hydrologists should lead in ensuring shared positive findings and suggested solutions to issues are implemented at their study sites.

It is recommended to issue questionnaires at the end of the workshop requesting feedback on the event. The questions should include:

1. What was most useful?
2. What was least useful?
3. Would the para-hydrologists like a further workshop? If so, when?
4. What would the para-hydrologists like a subsequent workshop to include?

9. Community feedback workshop

On an annual basis, the CBM organisers and the para-hydrologist should organise a workshop at the study site for the local community. A suitable central location for the workshop must be located, with shade from sun or rain if it is held outside. Consider providing drinks and snacks in accordance with local customs. The aim of the workshop is to provide and receive feedback on the citizen science programme. Research in East Africa by Comte et al. (2016) indicated that local stakeholders are critical of researchers who commonly do not share project findings. A workshop will show the community that their hard work is appreciated and has a purpose. The findings should encourage more informed decisions on land and water resource management. These workshops should be run by the para-hydrologist; that is the para-hydrologist should arrange the time and location and invite the attendees. As many community members as are interested, in addition to the observers, should be encouraged to attend. It is important to plan the workshop for a day and time that does not exclude any particular group. For example, be aware that farmers may be unable to attend during harvest periods, youth cannot attend during school hours, while certain days and times may be preferable for women and pastoralists.

Feedback and queries may be posed by the CBM organisers, which the para-hydrologist should then relay to and from the community in the local language. Data should be presented as clearly and simply as possible using large plots as well as any other creative visual aids that can be thought of (Figure 13); the CBM organisers may have to prepare these materials. As projects progress, any findings linking rainfall or land use change (including land degradation interventions) to water availability or crop yield would be

(a) (b)

FIGURE 13: Community feedback workshops in Ethiopia. (a): Discussing differences in well responses (the blue cut outs represent water level in monitoring wells). (b): Presenting river flow time series plots. Photos from: David Walker.

particularly interesting to rural communities. The workshops are an opportunity for the community to query aspects of the programme, to provide further hydroclimatic observations, and, most importantly, to increase their own understanding of their water resources. Additionally, queries can be put to the community to help explain any unusual monitoring data, such as jumps in time series or unexpected patterns and relationships. From our own experience, such queries have proved invaluable in understanding groundwater level fluctuations prior to use of the data in modelling and recharge studies.

10. Summary

The purpose of this guideline is to give guidance on the selection, training and managing para-hydrologists to ensure the successful running of a citizen science hydroclimate monitoring programme. Background information was provided about the history of para-hydrologists, which have emerged from other types of "barefoot scientists". The reader is reminded to consult the *First CBM Guideline* with regard to the overall planning, establishing and operating of a CBM programme (Walker et al., 2019).

High importance must be given to the selection of a para-hydrologist to ensure the effectiveness of CBM. The selection criteria are detailed in Section 3. A para-hydrologist will require greater training than observers who collect the data. This guideline describes the required training and additional equipment. The role of the para-hydrologist is detailed explaining both the regular and infrequent duties. Capacity building workshops are recommended bringing together para-hydrologists from different study sites. Topics for presentation and discussion were suggested. Finally, the importance of community feedback workshops was highlighted to provide project findings and gain feedback from the study site community.

As stated in the opening "Purpose and scope" section: This document and the *First CBM Guideline* have been developed following research in Ethiopia since 2014 and in India since 2016 where multiple study sites have had community-based, or citizen science, monitoring (CBM) implemented using an iterative process leading to continual improvement of the methodology. In addition, the guidelines consider successful CBM in the UK and South Africa which have informed and been informed by the Ethiopia and India research.

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