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Applying Citizen Science for Sustainable Development: Rainfall Monitoring in Western Nepal

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We introduce a case-study agnostic framework for the application of citizen science in a sustainable development context. This framework is tested against an activity in two secondary schools in western Nepal. While the purpose of this activity is to generate locally relevant knowledge on the physical processes behind natural hazards, we concentrate here on its implementation, i.e., to obtain a better understanding of the dynamic of the activity and to learn how it should be implemented. We determined the social capital of secondary schools as a gateway to the local community: they provide a unique setting to bring different stakeholders together. We find that co-designing a teaching programme is an effective means of both complementing local curricula and ensuring continued buy-in of local stakeholders (i.e., teachers). Student engagement depends on the local relevance of teaching materials, with more holistic or global concepts, such as climate change of lesser importance. Our activity focused on rainfall, including student-led data collection. These rainfall data provide a very good fit to co-located rain gauge data, with an average difference on weekly readings of 11.8%, reducing to 8.3% when averaged over all student readings. The autonomous development of student-organized science clubs suggested that our original framework underestimated students' capacity to apply knowledge elsewhere creatively. These clubs may be used to obtain participant feedback to improve and tailor future activities. Quantitative assessment of long-term sustainability remains challenging, due in part to high levels of student turnover. We suggest that integrating scientists wherever possible within a school or local community has a direct and positive result on participant retention.

Keywords: sustainable development, secondary education, precipitation, participatory monitoring, citizen science

KEY POINTS

- We present a framework to apply citizen science in a sustainable development context.
- The framework is tested and refined using an activity in two schools in western Nepal.
- Student-measured weekly rainfall totals are typically within 10% of the rain gauge values.
- Teachers should be involved in co-developing lesson plans to enhance sustainability.
- Informal student-organized science clubs emerged, which develop rapidly and organically.

INTRODUCTION

Citizen Science Research Projects

As environmental science and the human development actions increasingly address key challenges in the context of social-ecological systems, there exists a pressing need to understand better how people perceive, operate, learn, and take decisions within those systems. It is increasingly recognized that citizen science can play a role in this process (Buytaert et al., 2014). We define citizen science as scientific research that is carried out by the general public, often in collaboration with professional scientists affiliated to a university or research organization (e.g., Haklay, 2012). Research projects that exploit citizen science also have the potential to mobilize people's involvement in social action and justice, information development, and large-scale information gathering; attempts have been made to formalize the wide variety of terms and expressions that are frequently invoked in the field (e.g., Eitzel et al., 2017). Positioned as a means to accomplish education and conservation science, citizen science projects have increased exponentially in the last decade; it is widely accepted as a fast and economical means of bringing scientific data collection to scale (e.g., Bonney et al., 2014; Theobald et al., 2014; Le Féon et al., 2016; Paul et al., 2018).

Over the past 15 years, technological innovations, such as increasingly sophisticated smartphone apps have enabled citizen scientists to record (or crowdsource) millions of observations of, for instance, the occurrence of seismic activity, or flood duration, magnitude and extent (e.g., Rochford et al., 2018; Seibert et al., 2019). To date, relatively few of these projects have been conceived in developing countries, owing to a range of complex and interrelated hurdles including a lack of local capacity, bureaucratic and financial barriers, inaccessibility, and poorly understood citizen motivation and institutional hierarchies (Bonney et al., 2015; Lukyanenko et al., 2016).

The challenges of citizen engagement and participatory monitoring programmes are increasingly well-documented, including citizen incentivization and project sustainability; and highly variable data quality (in terms of accuracy, completeness, and timeliness) that does not always conform to professional scientific standards (e.g., Bonney et al., 2015; Lukyanenko et al., 2016; Guerrini et al., 2018; Irwin, 2018). Moreover, Bonney et al. (2015) note the difficulty in ascribing "success" to citizen science initiatives; they are often viewed by the professional scientific establishment as "high-risk," rarely achieving all objectives in

terms of enhancing public awareness of science, contributing to societal well-being, or providing high-quality, extensive, distributed datasets.

The emerging shift from crowdsourcing (also described as "number-crunching" by Irwin, 2018, or "citizens-as-sensors" by Goodchild, 2007) to more active roles in analysis and interpretation has the potential to enhance and enrich citizen involvement through the entire life-cycle of a research project. In turn, this more active involvement can increase decision-making capacity by enhancing local uptake. However, major hurdles remain in terms of embedding citizen science projects and data into governmental development agendas (Cieslik et al., 2018; Paul et al., 2018).

To avoid that citizen science be seen as a panacea to longstanding agricultural, economic, or social problems suffered by community-level stakeholders, or as an alternative to established programmes that build resilience to natural hazards, it is important to consider it a useful new modality that complements the existing toolkit in such efforts (Cieslik et al., 2018; McCampbell et al., 2018; Paul et al., 2018). In developing countries, and especially in a sustainable development context, citizen science initiatives are often community-based and -led; policy acceptance at higher levels remains poor due to a series of complex and interconnected challenges, such as lack of institutional capacity, mistrust of the motives of project leaders, and potential overlap with existing initiatives (Irwin, 2018; Hecker et al., 2019). Elsewhere, the Extreme Citizen Science (ExCiteS) research group at University College London (UCL) explicitly interrogates the barriers and opportunities toward operationalizing and scaling up citizen science in developing countries (e.g., Stevens et al., 2014).

Participant Motivations Across Geographic and Temporal Contexts

Even though a number of citizen science projects adopt a global perspective (i.e., addressing the sustainable development goals; Fritz et al., 2019), participant motivation differs significantly between developed and developing country settings. While in Europe and North America citizen-participants enjoy the opportunity to spend time in nature with their friends and families and enhance their relationship with the natural world (Rotman et al., 2014), for citizen-participants in low- or lower middle-income countries, this form of volunteerism is less evident. In a recent paper on citizen-scientist motivations in Sierra Leone, Larson et al. (2016) report that nearly all participants referred to financial compensation as the greatest source of motivation for contributing environmental observations, as "*nearly half of the participants stated they would not voluntarily share information to future researchers without compensation for their time.*" They also comment that apart from direct payment, community development and infrastructure like roads, wells and schools were considered sufficient incentives.

While compensating citizen-scientists for their effort remains rare, some citizen science projects in developing countries strive to meet local needs by targeting relevant socio-environmental problems of the local communities, including ecosystems change,

resilience to natural hazards and agricultural intensification (Pocock et al., 2018). Despite strong action-oriented framing, however, the potential of science-driven projects to respond to local needs in a timely manner and provide actionable knowledge remains limited (Cieslik et al., 2020).

Citizen-participant motivation also varies across time scales. Rotman et al. (2014) found that even though initial participation in citizen science projects may be fueled by personal interest and altruistic drivers, continued involvement was conditional to merit attribution and acknowledgment. Participant retention is an ongoing challenge for most citizen science projects: largely longitudinal in design, few projects have maintained volunteers' engagement over time.

Citizen Science in Education

In the context of formal education, citizen science has much to offer as a means of making Science, Technology, Engineering, and Mathematics (STEM) learning accessible, relevant, and meaningful (Ballard et al., 2017). Youth and educators can take part in real-world science that is engaging, that responds to their interests, and that makes connections between science and the world around them, as well as fostering youth participation in current land conservation actions, building their capacity for future conservation actions.

Many studies have reported time-limited interventions in schools that involve a component of teaching, often in the realms of biology or conservation (e.g., Le Féon et al., 2016; Shah and Martinez, 2016; Bracey, 2018). Ideally, such interventions involve the co-generation of new scientific data; for instance, the collection and classification of bees at 20 secondary schools in France (Le Féon et al., 2016). This degree of interactivity ensures that information flow is two-way between the student participant and professional scientist, which has been shown to increase uptake and retention in citizen science projects (Paul et al., 2018). Saunders et al. (2018) note the important role offered by citizen science in school education. It engages students directly with environmental science, offers an understanding of the scientific process, and allows students to observe local representations of global challenges like efforts to mitigate against climate change. Numerous studies describe case studies in the United States specifically, where citizen science has been recognized as a means of enhancing both formal and informal science teaching and learning (e.g., Cooper, 2012; Shah and Martinez, 2016; Bracey, 2018). Indeed, Shah and Martinez (2016) report on the "unexplored" role of citizen science in the classroom, emphasizing its potential role in providing innovative pedagogical methods that could reform the U.S. educational system.

Acknowledging the diversity of motivations that drive citizen science projects is especially important from the point of view of monitoring and assessment. A project is generally considered successful if it manages to generate reliable citizen-sourced data over a period of time, but other benchmarks are also possible, including continued engagement, participant satisfaction and retention rates, knowledge sharing, awareness raising, inciting environmental activism and engagement (Johnson et al., 2014).

Against this background, in this study we target schools as a setting for a citizen science project, to address a number of potential pitfalls (Haywood and Besley, 2014). Since students perform the data collection activities as part of their school curriculum, they are intrinsically motivated and time-unconstrained. The school setting also provides continuity throughout the academic term and generational succession. In developing countries, teachers are generally among the most knowledgeable and respected community members, while children are enthusiastic receptors of new information, which can then be reported back to parents (Cieslik et al., 2019). Finally, skill training and results dissemination allow integration of the educational objectives in a classroom setting, ensuring societal outreach.

Motivation of the Study

Citizen science has been widely recognized as an effective means of large-scale data collection while also offering novel routes into non-scientist engagement and pedagogy. However, few studies have placed this analysis in a development context (Schuttler et al., 2019). Here, we explore the development of a literature-grounded framework for citizen science in such a context, testing it against a case study of two secondary schools in western Nepal. We seek to operate in the shared space between science and education, i.e., generating new scientific data while also enhancing local environmental awareness (Paul et al., 2018; Cieslik et al., 2019). In addition, we explore how to enhance the longevity of citizen science activities (**Figure 1**) at a community level. More practically, we aimed to develop students' knowledge of the scientific method of structured data collection, as well as practicing the interpretation of data (validity, reliability, accuracy, generalizability, etc.).

We sought to address three points: first, to understand the usefulness and applicability of a framework to guide citizen science in a developing (rather than developed) country; secondly, to explore the potential of citizen science in the disciplines of meteorology and its relation to natural hazards (rather than the fields of biology/ecology); and finally, to maximize the continuing relevance and long-term sustainability of the intervention (rather than a one-off or time-limited survey). Our goal is to analyse the successes and bottlenecks of translating theory into practice at a local level, in order to refine the framework to a set of generalizable and replicable standards. We executed our case study "testbed" in May 2019. Specific local aims were to:

- Sensitize students to aspects of the genesis of natural hazards (Monsoon rains and flooding) in their immediate environment;
- Reinforce STEM education in the schools, and strengthen knowledge about the physical processes underlying natural hazards;
- Collect precipitation data for comparison to a nearby automatic tipping-bucket rain gauge dataset (i.e., an "experiment");
- Generate locally relevant scientific knowledge for development, i.e., generate local data that are of sufficient

quality to be used in decision-making processes on resilience creation to natural hazards.

The specific contribution of this paper is as follows: first, we develop a conceptual framework for designing and conducting citizen science activities for young learners in development contexts. We summarize learnings from the literature and critically assess both the feasibility and salience of involving communities in participatory environmental monitoring. Secondly, we illustrate our model with a case study of a rainfall monitoring project conducted in western Nepal in two local schools. Contrary to the mainstream technocratic approach that relies on ICTs and low-cost connectivity, we demonstrate how the use of locally available tools and instruments can provide accurate and robust environmental measurements of scientific quality. Thirdly, we complement our framework with ready-to-use visuals and lesson plans that allow for future replications of our model by scientists and educators alike.
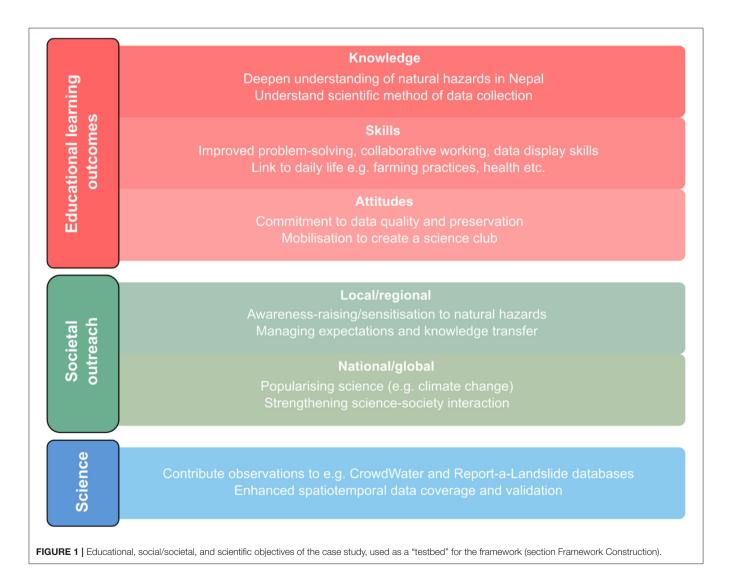
The remainder of the paper is structured as follows. In section Methodology, we describe the construction of our framework and then test it using a case study of two secondary schools in western Nepal. Section Results and Discussion discusses the results of this field experiment, including practical experience of implementing our framework, as a means of refining its validity and applicability. We provide brief conclusions and a future outlook in section Conclusions and Outlook.

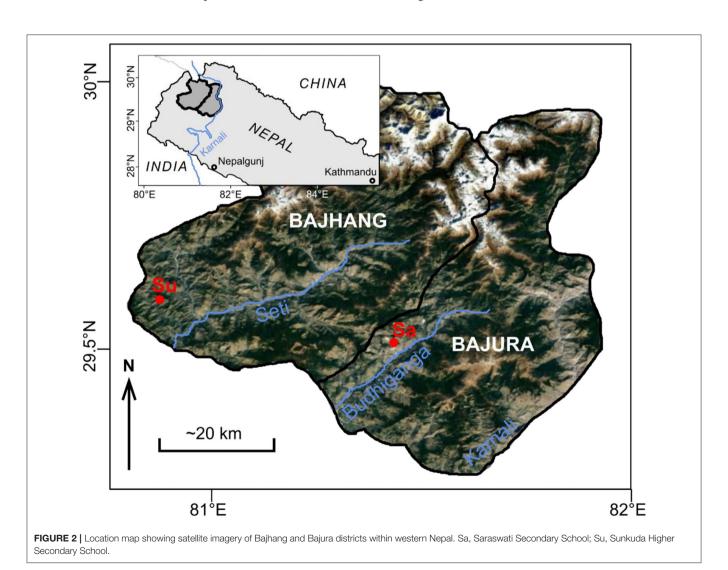## METHODOLOGY

Framework Construction

Citizen science in its broadest sense may be grouped into three phases: planning, implementation, and assessment (e.g., Bracey, 2018). During the planning, analysis of teachers' expectations and motivations is a widely recognized precondition to citizen science interventions in schools (e.g., Haywood and Besley, 2014; Bracey, 2018; Pocock et al., 2018). The power of such interventions to enrich local curricula has only recently been recognized: it critically depends on the manner of framing or presentation to teachers and students alike (Shah and Martinez, 2016).

Educational learning outcomes

Knowledge
Deepen understanding of natural hazards in Nepal
Understand scientific method of data collection

Skills
Improved problem-solving, collaborative working, data display skills
Link to daily life e.g. farming practices, health etc.

Attitudes
Commitment to data quality and preservation
Mobilisation to create a science club

Societal outreach

Local/regional
Awareness-raising/sensitisation to natural hazards
Managing expectations and knowledge transfer

National/global
Popularising science (e.g. climate change)
Strengthening science-society interaction

Science
Contribute observations to e.g. CrowdWater and Report-a-Landslide databases
Enhanced spatiotemporal data coverage and validation

FIGURE 1 | Educational, social/societal, and scientific objectives of the case study, used as a "testbed" for the framework (section Framework Construction).

Action-oriented framing—for instance, focusing on combating relevant local socio-environmental problems—has been shown to enhance uptake and participant retention in developing countries (Larson et al., 2016; Pocock et al., 2018; Cieslik et al., 2020). We therefore posit two routes toward enhanced buy-in: (a) co-development, with teachers, of lesson plans and teaching materials that complement local curricula; and (b) framing teaching and data collection in the context of relevant local environmental challenges, such as flooding and landslides.

During implementation of a specific activity, the physical presence of professional scientists has been noted as favorable to both educational and scientific outcomes of many citizen science projects (e.g., Le Féon et al., 2016; Shah and Martinez, 2016; Saunders et al., 2018). Based on post-intervention student interviews, several explanations have been offered (e.g., Haywood and Besley, 2014; Le Féon et al., 2016): the presence of scientists serves as a permanent reminder of the importance of the newly introduced teaching material; participants seek competitively to impress the scientists with increased diligence and attention; and the scientists themselves serve as positive societal role models.

In response to these findings, we postulate that professional scientists should be embedded in the social structure of the school as closely as possible. In terms of the activities, students have been shown to be more engaged when a variety of different teaching methods is practiced (e.g., Le Féon et al., 2016). Davids et al. (2019) argue that environmental learning is most effective when local problems, such as Monsoon flooding are placed within a global context, e.g., of climate change. Student-led data collection activities, involving varying degrees of training *a priori*, are likewise a typical component of citizen science interventions in schools (Le Féon et al., 2016; Bracey, 2018; Saunders et al., 2018; Davids et al., 2019). Such co-generation of new scientific data and its dissemination constitutes two-way information flow between scientist and student participant, which enhances uptake and retention rate (e.g., Buytaert et al., 2014; Paul et al., 2018; Cieslik et al., 2019). We therefore propose that activities be balanced equally between classroom teaching, technical training, and scientific data collection. Teaching material should focus on local relevance, but should also be situated within a global context.

FIGURE 2 | Location map showing satellite imagery of Bajhang and Bajura districts within western Nepal. Sa, Saraswati Secondary School; Su, Sunkuda Higher Secondary School.

Less has been paid to the assessment of citizen science interventions, specifically ways in which knowledge generated during citizen science interventions can be sustained (Bracey, 2018). Ballard et al. (2017) emphasize the time-limited, one-off nature of many interventions, usually serving a specific aim that is tied to those of a scientific research project, either in data collection (via crowdsourcing: e.g., Le Féon et al., 2016; Rochford et al., 2018) or outreach (Davids et al., 2019). Participant retention has been recognized as the single most important bottleneck in many citizen science initiatives (Bonney et al., 2015; Gharesifard et al., 2019).

The assessment of citizen science activities is accepted as being of equal importance as the activities themselves, and has been shown to enhance the livelihood relevance of citizen science projects (beyond schools), thus enhancing retention and even allowing such projects to expand via word-of-mouth (e.g., Goodchild, 2007; Haywood and Besley, 2014; Cieslik et al., 2018; Rochford et al., 2018). Based on these findings, we postulate that interviews and questionnaires should be conducted *post-hoc*, the results of which could serve to tailor the local relevance of potential future activities (cf. Kimura and Kinchy, 2016).

Case Study

Two study sites were chosen targeting local communities vulnerable to flood and landslide hazards. In a remote region of the Lesser Himalayas of western Nepal, these were the municipalities of Sunkuda, Bajhang district; and Bajedi, Bajura district (**Figure 2**). The geological characteristics of these two sites are described in detail elsewhere (Cieslik et al., 2019).

We first identified appropriate secondary schools over the course of three field trips in 2018–2019 based on the following criteria. First, the student cohort needed to be of appropriate size (>20 students in one session) and age (14-/15-years-old, or class 9 and 10 in the Nepal secondary school system, are the most senior students in education through the entire academic year; older students typically take more time off to assist parents with farming activities). Moreover, previous exposure to NGOs or even citizen science initiatives was favorable because roles could more easily be defined and understood, and expectations managed. Lastly, it was thought essential that schoolteachers understood and were enthusiastic about the overall hydrological risk reduction objectives of the initiative. Based on these criteria, as well as proximity to landslides, springs, or rivers, one secondary school at each study site was chosen: Saraswati Secondary School in Bajura, and Sunkuda Higher Secondary School in Bajhang (**Figure 2**; **Table 1**).

We tested our framework (section Framework Construction) at these schools, first developing a set of learning activities for the students (classes 9–10: 14-/15-years-old) that included interactive classroom teaching and data collection. In addition to educational and social objectives (**Figure 1**), the intention of the case study was also to support scientific data collection. As far as possible, we sought to introduce material at a commensurate level with the Government of Nepal (GoN)'s approved curricula on Science for secondary grades. Working with teachers, we identified areas where our intervention could complement the curricula while maintaining local relevance.

TABLE 1 | Information relating to each school, sourced *a priori*.

School name	Saraswati Secondary School	Sunkuda Higher Secondary School
Address	Chhededaha-07, BAJURA	Sunkuda, BAJHANG
Coordinates	29°25′9″ N, 81°19′55″ E	29°30′13″ N, 80°51′5″ E
Preferred session timing	0.5–3 days	Up to 3 days
Best time for intervention?	End-Jan to mid-Feb; and late-Apr to May (exams Mar–Apr)	Mid-April to June
Would students be interested in project? (asked to teachers)	Yes because school located in landslide-affected area; rainfall causes landslides; no component on hydrology in Nepali curriculum	Yes; it would complement advanced ICT lessons
Strength of local phone signal	Moderate to strong (2G coverage only)	Strong (good 3G coverage for entire school)
Local geography	Gumla landslide ~2.5 km away; Budhiganga river ~1.5 km away	400 m to major landslide. Numerous small springs; school on steep valley side overlooking river (2 km below)
Commitments	Teachers willing to engage for >3 years, depending on outcomes of initial sessions, if we can build activities into curriculum	Two student helpers and one teacher (ICT specialist) will be available for long-term commitments
Possible teaching venue	Main school hall; school ground	School hall; science classroom
Nearest guest accommodation	Onsite stay possible in school hall	Guest room in Deulekh (1 km); good hotel in Deura (10 km away)
Internet/electricity	No/solar only	Yes/yes (grid and generator)
Student cohort	Class 1–10; classes 9 and 10 (14-/15-years-old) = 61 students	Class 1–12; classes 9 and 10 (14-/15-years-old) = 280 students
What do teachers teach?	Maths, science, environmental studies (including floods and landslides), health studies	Maths, science, environmental studies, computer studies (ICT)
Other details	This school has already formed after-school clubs and has organized activities like whole-school sanitation and tree plantation	Prior exposure to NGOs, e.g., junior Red Cross and child club in place. Teachers keen for activities to contribute to academic syllabus and help with student scientific capacity building

Data collection in our citizen science activity focused on precipitation measurements for three reasons. First, concepts surrounding (Monsoon) rainfall are locally relevant, tangible, and relatively easy to explain, offering many opportunities for interactive quantitative exercises. Secondly, there is a paucity of ground-based rainfall measurements at a high spatial resolution in western Nepal (and southeast Asia in general: Khatiwada and Pandey, 2019). These data are crucial to increase understanding flood and landslide risk, which are two major natural hazards in the region. Lastly, the measurements can be easily corroborated

with data from automatic rain gauges. For this purpose we installed two tipping-bucket rain gauges on each school's roof in May 2018. Focusing on rainfall measurements therefore has the potential to enhance the theoretical grounding behind these installations.

Application of our Framework

We divide testing the testing of our framework into three phases: planning, implementation, and assessment, as is commonly undertaken in other citizen science projects in sustainable development (e.g., Bracey, 2018).

Planning

In the planning phase, we began by soliciting interest within our stakeholder consortium, before initiating an extensive consultation exercise with local educators at both schools, culminating in the development of Nepali-language lesson plans and teaching materials that would complement the schools' Science curricula. The intention was that the process be iterative: results from initial or pilot sessions should be used to inform the planning stage of future activities with students (cf. Shah and Martinez, 2016). The planning phase took 4 months and consisted of the following specific activities:

– Circulate concept note to project consortium; solicit interest and marshal ideas for potential school lessons and environmental data collection activities;
– Fieldwork to determine appropriate schools for intervention: ideal conditions include proximity to a potential hazard, e.g., landslide or river that floods regularly; previous exposure to NGOs or citizen science projects; fit to curriculum and school timetable; educators amenable to project objectives; correct number and age of student cohort;
– Co-develop lesson plans and teaching materials with educators and project scientists; translate into local language and dialect;
– Elicit consultations on all project materials in relation to the local context (in particular, linking the material with the appropriate-age national curriculum in environmental science);
– Skype meetings between project scientists to coordinate agendas and determine roles during student activities (e.g., developing oral scripts and planned graphs to draw on the blackboard, checking the veracity and relevance of quantitative exercises);
– Develop assessment forms and protocols per Bracey (2018) and Rochford et al. (2018) for iterative improvement of the citizen science activities.

Implementation

The next phase, implementation, was tailored to each school's timetable over the course of 2 days. Together with teachers, we developed five sessions for our intervention (**Table 2**). The delivery team comprised a mixture of three professional scientific researchers (two Nepali; one European), two Nepali facilitators from a facilitating NGO (Practical Action Consulting); and Science, ICT, or Geography schoolteachers. Activities with the students commenced with a brief introduction to the project and intended learning outcomes (in English; translated into Nepali), followed by a brief round of introductions from all participants.

Throughout the entire day of activities, interactivity with the student group (30 class 9/10 students in Saraswati, and 45 in Sunkuda) was encouraged through open discussion and question-and-answer sessions that emphasized the immediate local environment (e.g., asking students to locate their houses on a map; suggest reasons for landslide initiation; and debate whether the annual Monsoon rains were increasing or decreasing in magnitude, and whether this was a problem (or not) for their family). We distributed 15 manual measurement cylinders to students at each school that were successfully installed, with help from the schoolteachers, at suitably exposed locations, such as the roofs of students' homes. Students were given specific instructions about rigorous data collection, including the need for an accurate record at a given time each day, and measurement using the volumetric scale on the cylinder. Teachers then took photographs of students' daily rainfall records, which were promptly sent to other project researchers in Kathmandu for data quality control and analysis (monthly smartphone credit was provided to each school to this end).

Table 2 breaks down the activities over the course of the day, which mixed blackboard teaching with numerical examples, open discussion, and outdoor demonstrations (cf. the "mixed methods" of Le Féon et al., 2016). **Figure 3** is an example of one of the posters (in this case, focusing on the effects of Monsoon rainfall on triggering landslides) that were displayed throughout the day at each school and were used as interactive stimuli for teaching. The design was tailored for the students, with minimal text, bold colors, and attractive graphics (**Figure 3**). Lunch was provided by the research team and taken together; we also sought overnight accommodation as close to each school as possible to foster a sense of community and integration.

Assessment

Immediately upon the completion of our activities in May 2019, all project participants (i.e., instructors, educators, students, school authorities) were provided with comprehensive feedback forms. Feedback was solicited in three areas: timing and organization of the intervention, the local relevance of scientific content and data collection activities, and suggestions for additional activities that would enhance scientific capacity resilience creation to natural hazards. These forms and interviews will be completed and analyzed in relation to the project's objectives (**Figure 1**), which could then inform the structure of potential future activities (section Conclusions and Outlook).

RESULTS AND DISCUSSION

Findings of Case Study Activity

Planning, implementing, and assessing the citizen science activity yielded information about the activity itself, i.e., student engagement levels and the quality and volume of collected data.

TABLE 2 | Summary of student activities.

Session theme	Activities	Learning outcomes
A: Geographical context (30-min warm-up)	- Locate school and homes on poster map and satellite imagery on phone - Identify local geographical features like rivers, springs, landslides - Discussion on family migration	- Use various GPS-based location apps - Foster greater sense of environmental and spatial awareness (i.e., immediate landscape and hydrology) - Foster student-student knowledge transfer and interaction - Situate students' homes and schools within broader regional/national context - Situate the initiative as a scientific enquiry (managing expectations)
B: Rainfall (1 h)	- Teaching on Monsoon: patterns, provenance using worksheets and Q&A - Calculator exercises, e.g., adding up total annual local rainfall figures - Link to local livelihoods: importance of rainfall in farming, health, sanitation	- Importance of collaborative working and problem-solving using incomplete/fragmentary datasets - Ability to quantify rainfall totals—and the importance of figures/calculations - Increased scientific and cultural understanding of uniqueness of Monsoon rainfall
C: Hazards (1 h)	- What is the role of water in triggering natural hazards? - Open discussion about landslide perception - Demonstration of causes and triggers of landslides—outdoors - Photos of other natural hazards (e.g., 2015 Kathmandu earthquake)	- Awareness raising and sensitization to flood/landslide processes and associated risk - Awareness of variation in risk and vulnerability, and contributory factors - Behavioral change given certain early warnings
BREAK/LUNCH		
D: Rainfall trends (1 h)	- Open discussion about local harvests, rainfall—introduction to trends - Introduction (blackboard teaching) to climate change - Some worked examples with calculators	- Knowledge sharing: student/parent knowledge transfer - Farm-level information (scientific measurement) land lost to excessive flooding or landslides - Popularizing science (climate change) and strengthening science-society interaction
E: Measuring rainfall (2 h)	- What is the role of technology in understanding hazards and measuring water (rainfall and rivers)? - Interpretation of local automatic tipping-bucket rain gauges - Introduction to manual rain gauges (measuring cylinders) - Outdoor measurement exercises - Outdoor installation exercises - Fieldtrip to demonstrate measurement of river discharge	- Development of skills to locate and use available data sources in students' daily lives - Exposure to scientific data presentation and analysis - Develop understanding of structured data collection - Develop attitudes that support the responsible acquisition and application of scientific and technological knowledge to the benefit of self/society, and the environment - Continue rainfall data collection - Students are mobilized to create a landslide watch group or an environment club in their school to continue the environmental monitoring activities

Student Engagement

The intended deliverables were student-collected, daily-recorded precipitation datasets; establishing school-level science and environmental monitoring clubs; and ready-to-use lesson plans with accompanying teaching materials that complement the existing GoN curricula. After 6 months, 12 students continued to record and report data at Saraswati Secondary School; this figure was nine (of 15) students in Sunkuda Higher Secondary School. The nine students who discontinued measurements reported that the measuring cylinders were either stolen, vandalized, or lost due to high winds, rainfall, or livestock movement. Two of these students began to take measurements irregularly in the months prior to cessation. Student selection for manual rain gauge data collection was a source of pride; students worked hard to make accurate daily readings and secure the measuring cylinders to the ground/roof. It is clear that the established social structure of the school, where teachers have a well-defined role relative to the students, was essential in maintaining consistent data collection, as has been reported elsewhere (cf. Shah and Martinez, 2016; Saunders et al., 2018).

Data Collection and Quality

We compared the student data of weekly precipitation totals for the 2019 Monsoon at Saraswati Secondary School, Bajura, with a locally installed automatic tipping-bucket rain gauge (**Figure 4**). The results of the measuring cylinders agree very well with the rain gauge time series both in magnitude and time. The weekly cylinder measurements differ on average 9.4 mm week^{-1} with the rain gauge measurements, which is equal to a relative difference of 11.8%. This reduces to 6.7 mm week^{-1} (8.3%) if the measurements of all the students are pooled. When aggregated over the entire monitoring period, the difference between the rain gauges and pooled cylinder measurements is as low as 82 mm (2.9%).

In a similar experiment, Davids et al. (2019) describe the use and deployment of repurposed soda bottles for citizen-led rainfall measurements in the Kathmandu Valley. They report a 2.9% error between 154 rainfall measurements and automatic rain gauge data, ascribed to evaporation, condensation, and observational errors.
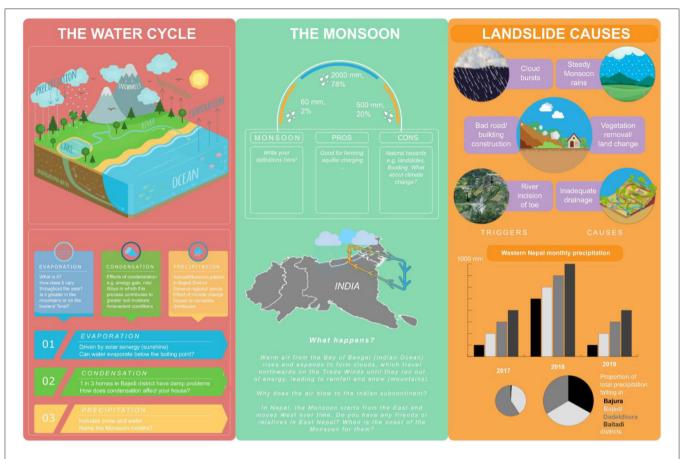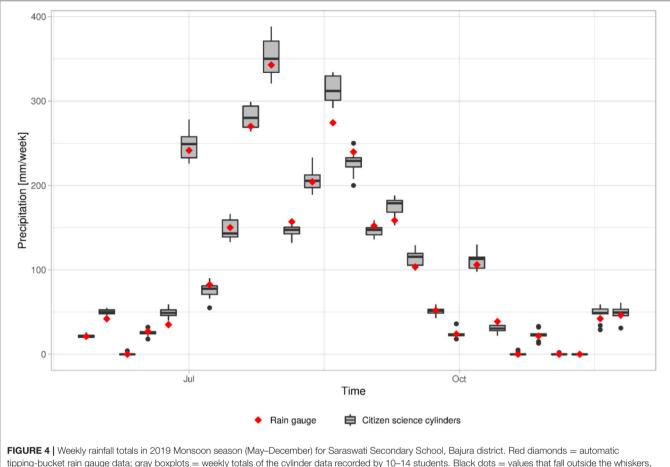
FIGURE 3 | Poster before translation into Nepali, used during the Rainfall session (**Table 2**) as a primer for discussion between facilitators and students about Monsoon rainfall. In the first instance, students were asked to write on the poster their own suggestions about the causes, challenges, and potential benefits of the Monsoon. One identified "challenge" was landslides, which led onto the next session (Hazards), where facilitators used the right-hand panel of the poster to teach landslide antecedents (e.g., heavily saturated soil or friable bedrock) and triggers (e.g., cloudbursts or deforestation).

Evaluation of our Framework

The application of our framework to a specific case study yielded valuable information about its broader applicability and ability to capture properly the impact of the activity (and also, by extension, whether certain effects were missed). We now reflect on lessons that were learned from our experience of translating the generic framework into practice, in order to refine and improve it. In the first instance, the process of co-developing teaching materials that would complement a specific science curriculum was straightforward. From the local teachers' perspective, this was the most salient aspect of our activity, demonstrating the value of their intrinsic involvement throughout the entire life-cycle of such citizen science projects. We found strong complementarity between a fit-to-curriculum and the action-oriented framing of Larson et al. (2016): new learning material introduced to students can be useful both in enhancing their knowledge of prescribed curricula, and in augmenting understanding of the immediate environment (in our case, river development, hillslope processes, and rainfall patterns).

In our framework, we postulated that the physical presence of professional scientists would enhance learning and participant retention. However, in practice, there are few opportunities for such active involvement other than brief (and translated) introductions; students respond more readily to their own schoolteachers, rather than to members of a scientific team. A suite of different scenarios where scientific involvement is varied (i.e., teaching delivery entirely by professional scientists, to none being present at all) would be necessary to evaluate this factor. In terms of our intervention, we found that the continued involvement of teachers extended to their willingness and ability to lead classroom-based sessions (rather than a professional scientist, which we theorized would have greatest impact). The framework should therefore be refined to place greater emphasis on teaching delivery by existing staff. We then analyzed the effect of scientist engagement levels on student retention. While a greater number of students continued data collection activities when we could to integrate more closely with the school and local community (e.g., staying overnight in the school hall, and

FIGURE 4 | Weekly rainfall totals in 2019 Monsoon season (May–December) for Saraswati Secondary School, Bajura district. Red diamonds = automatic tipping-bucket rain gauge data; gray boxplots = weekly totals of the cylinder data recorded by 10–14 students. Black dots = values that fall outside the whiskers, which represent 1.5 times the interquartile range. The mean of the absolute difference between the average of all cylinders reading in a week, and the corresponding rain gauge reading, is 6.7 mm week^{-1} (minimum = 0 mm week^{-1}; maximum = 38.7 mm week^{-1}).

eating communally with students), additional evidence is needed to establish robustly this theoretical causality (e.g., a greater number of tests with rigidly defined levels of integration: Saunders et al., 2018).

We sought to identify topics of local relevance for students *a priori*; direct measurement of student engagement (relative to, e.g., more holistic concepts, such as climate change) is challenging and has been little explored outside secondary schools in a few developed countries (e.g., Rochford et al., 2018; Saunders et al., 2018).

In the assessment phase, we posited in our framework that student-led "science clubs" represent a means of fostering long-term sustainability. In practice, such groups are more likely to evolve organically with minimal input from a scientific team; in our case study, this process took the form of informal weekly gatherings to collate rainfall measurements. Our framework did not capture the development of a system of monetary prizes for the "best" student data, judged on criteria, such as legibility, accuracy, consistency, and student conscientiousness. This took place independently of data collection and teaching activities and was not directed by project researchers; rather, teachers took the

initiative to set up the prizes in order to motivate students to complete their assignments diligently. In future, funding for the prizes could be disbursed during future interventions, to support retention and incentivize continuing data collection. Moreover, we did not envisage a significant externality resulting from the clubs: students also report other environmental metrics (e.g., rice terrace cambering, or development of cracks in the ground) that are well-beyond the scope of our original instruction. The natural development of such information collection suggests that our framework underestimated students' capacity to apply new knowledge elsewhere in a creative manner.

Finally, following common practice in other, non-school-based citizen science initiatives (e.g., Goodchild, 2007; Haywood and Besley, 2014), we also theorized that the results of *post-hoc* questionnaires should allow the implementation of an activity to be improved iteratively (section Framework Construction). This process indeed yielded insights into retention levels or reasons for data collection cessation (such as equipment loss or vandalism, or simple lack of motivation; section Student Engagement). However, the high level of teacher and student turnover is an unforeseen bottleneck that could diminish the "institutional

memory" of citizen science activities; also, the GoN's secondary science curricula have experienced dramatic changes in content since federalization in 2017, which could present additional challenges to future continuity in this instance (Davids et al., 2019). Furthermore, we have not yet been able to assess quantitatively the longevity of the science clubs, nor the long-term sustainability of our activities. Our theoretical intention was that feedback solicitation should pose identical scientific questions (such as "when is rainfall heaviest in the year?"; "what are the main causes of river floods?") to respondents in the questionnaires to quantify knowledge and behavioral change (sensu Shah and Martinez, 2016). Instead, one solution could be to consult members of the "science club." While these students will naturally change over time, measuring the retained knowledge in each school is a more practical means of obtaining feedback that can be used to tailor future interventions to reflect more closely students' motivations and livelihood needs.

CONCLUSIONS AND OUTLOOK

We describe the development of a framework designed to guide citizen science projects in a sustainable development context. We tested the framework by means of a case study at two secondary schools in Nepal, in order to interrogate which elements could successfully translate from theory to practice, and to identify major challenges requiring further refinement. Schools were chosen as a useful "testbed" as they offer an established social structure, ready-made organizational capacity, and high social capital that can usefully be harnessed by a citizen science approach. Our focus on natural hazards (Monsoon and landslides) fulfilled the dual purpose of complementing scientific data collection and improving long-term scientific capacity. Indeed, the student-collected rainfall data provide an excellent fit to gauge data of the 2019 Monsoon, suggesting that our activities could be scaled up to provide good-quality citizen science data elsewhere.

However, our primary aim was to interrogate the implementation of the activity, in order to obtain a better understanding of its dynamics and to learn how it should be implemented. In the planning stage, the involvement of teachers in co-developing learning material was important to secure complementarity between a fit to the local curricula and action-oriented framing, which engaged students. We did not foresee the organic, unregulated development of student-organized science clubs, suggesting that our original framework underestimated students' capacity to apply new knowledge elsewhere creatively. One improvement could be to use these clubs to obtain participant feedback, to ground future activities in greater local importance and foster sustainability. Quantitative assessment of project longevity remains challenging, due in part to high levels of student and teacher turnover.

Our findings and refined framework are generalizable to other student populations, and can be used to guide the application of citizen science in a sustainable development context elsewhere. We plan to complete additional activities (related more explicitly to landslides) at the same schools, which will form additional case studies or "testbeds" to augment and further improve our framework.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

JP drafted the text and prepared the figures. KC, AD, and JP originated the concept. WB and KC provided the input to the structure, text, and figures. JP, NS, PS, BP, and SP executed the field activity, for which we also acknowledge the assistance of Caroline Russell, Clara Rodriguez-Morata, and Alberto Munoz Torrero Manchado. All authors contributed to the article and approved the submitted version.

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