Mobile phone technologies for disaster risk reduction

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ABSTRACT

The explosion of increasingly sophisticated mobile phone technologies can usefully be harnessed by disaster risk reduction (DRR) as a means of enhancing inclusivity and local relevance of knowledge production and resilience building. However, much new technology is designed on an ad hoc basis without considering user needs – especially mobile applications (apps), which often terminate at the proof-of-concept stage. Here, we examine best practice by marshalling learnings from 45 workers representing 20 organisations working globally across the disaster risk management (DRM) lifecycle, including physical and social science, NGOs, technological developers, and (inter)governmental regulatory bodies. We present a series of generalisable and scalable guidelines that are novel in being independent of any specific natural hazard or development setting, designed to maximise the positive societal impact of exploiting mobile technologies. Specifically, the local context, dynamics, and needs must be carefully interrogated a priori, while any product should ideally be co-developed with local stakeholders through a user-centered design approach.

1. Introduction

The diversity and sophistication of mobile phone technologies have developed rapidly over the past 20 years, especially in emerging economies. Coupled with the increasing usage of mobile devices worldwide, about 95% of the global population is now covered by mobile signals (GSMA, 2020a), while smartphone ownership rose to over 600 m and 820 m in sub-Saharan Africa and India, respectively, in 2020 (GSMA, 2020a, 2020b). This increased availability of mobile phone saturation cuts across societal segments, opening up new ways of gathering big data, accessing environmentally relevant information, and fostering positive societal interventions, all of which are important in Disaster Risk Reduction (DRR). The work of scientists and policy makers has been profoundly impacted by unprecedented enhancements in spatiotemporal data coverage (van Vliet et al., 2014; Price and Shachaf, 2659; Paul et al., 2018). Today's mobile phones may be equipped with sensors that can be utilised for scientific observation, while mobile networks can be exploited to transmit physical observations and measurements from users to the pre-designed scientific domain (Cooper et al., 2007; McCabe et al., 2017).

The interaction of mobile-wielding non-scientists with professional scientific research falls under the rubric of citizen science; other definitions exist that might explicitly reference the spatial nature of the generated dataset (e.g. volunteered geographic information – VGI), or the way in which it was collected, such as crowdsourcing or 'people-as-sensors' (Goodchild, 2007; Eitzel et al., 2017). As

strongly advocated by the Sendai Framework on Disaster Risk Reduction (United Nations, 2015), linking data analysis to mobile phones and tablets allows people-centred decision-support systems to be constructed, which can increase long-term DRR capacity by tailoring risk and hazard information to a particular context or group of people, enhancing local relevance (Fritz et al., 2019). Mobile technologies therefore align well with the principles of citizen science: there is potential to make knowledge creation and resilience building more multidirectional, inclusive, and decentralised; mobile users can gain agency and empowerment over their immediate surroundings; and extensive, real-time information for risk management can be rapidly generated and disseminated (Paul et al., 2018; Lukyanenko et al., 2016; Guerrini et al., 2018; Irwin, 2018).

Since the early 2000s, mobile technologies have been used throughout the disaster risk management (DRM) cycle and are active before, during, and after a disaster. Much attention has been paid to the tangible and highly visible role of mobile phones in emergency response: increasingly seen as a means to chronicle events being witnessed and/or experienced personally, they are also commonly used to disseminate information and educate and inform the public and emergency services (Gething and Tatem, 2011). By harnessing the viral capacity of such technologies, emergency response teams are able to alert and locate those in danger more swiftly than via traditional broadcast media or telecommunications methods (Laituri and Kodrich, 2008).

Yet the potential of mobiles in the DRR realm has only recently been recognised and documented; a process that has been accelerated by the proliferation of context-specific DRR mobile applications (apps). Nevertheless, there exists a spectrum of different technologies that could usefully be exploited for DRR (Fig. 1). In areas of poor Internet provision and/or depressed smartphone ownership, voice calls and SMS messaging are used to target broad swathes of the population; for instance, Monsoon flood alerts for certain rivers in Nepal and India, sent by each respective country's governmental water bureaucracy (Pandeya et al., 2020). For Internet-connected smartphones, social media platforms such as Twitter and Facebook, as well as messaging services like WhatsApp, while commonly associated with emergency response, also offer an important channel for official hazard warning communications, and may also augment social capital (Kaigo, 2012; Agahari et al., 2018). Similarly, Geographic Information System (GIS)-based technologies represent another (spatial) means of risk communication. Google Maps, for instance, has been used to develop a user-led disaster management system in Bangladesh (Sonwane, 2014). OpenStreetMap (OSM), an open-source and collaborative GIS platform, has also been used to develop similar systems (Rahman et al., 2012), or to allow affected communities to generate local landslide hazard, risk, and vulnerability maps dynamically (Parajuli et al., 2020). However, the most commonly utilised mobile technology in
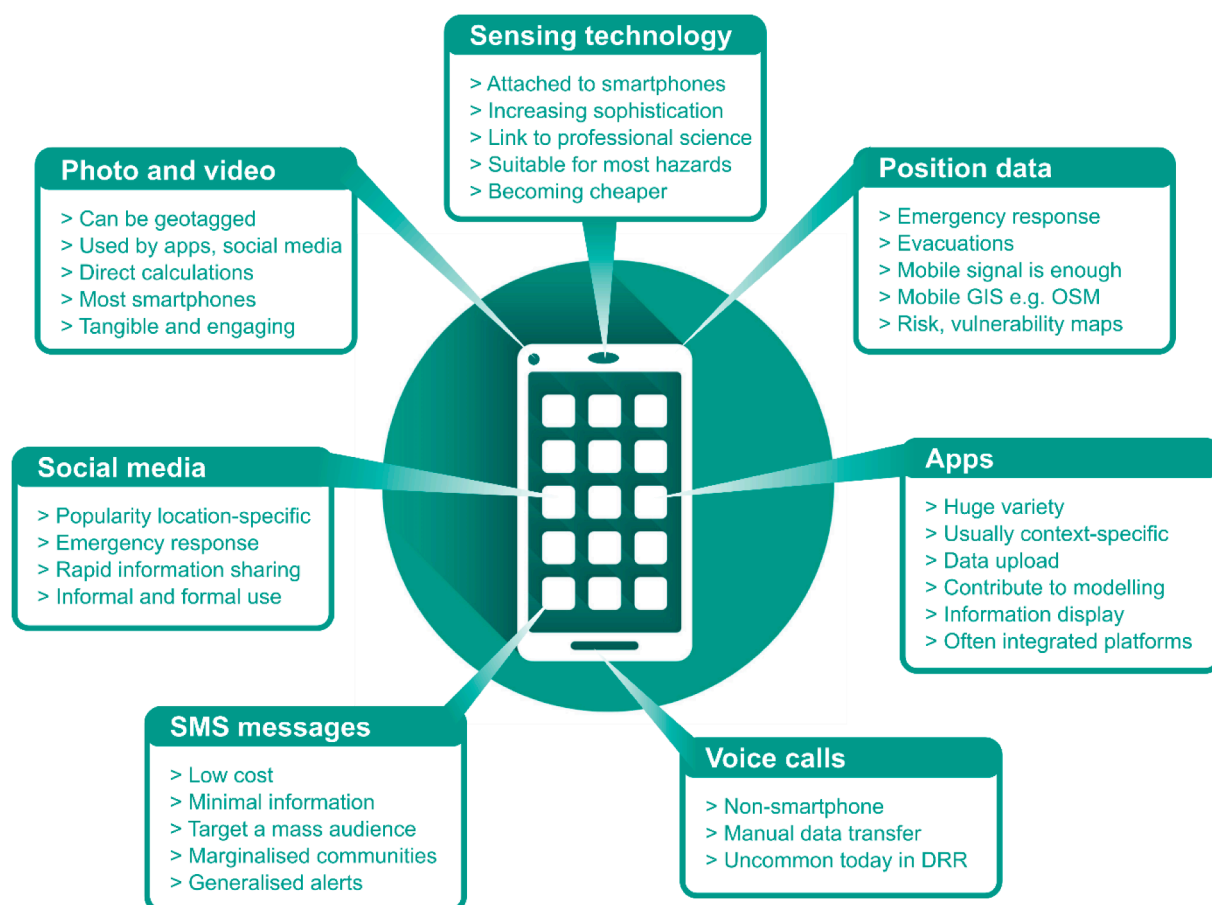

Fig. 1. Different mobile phone technologies leveraged by DRR.

DRR are apps: they provide a user-friendly means of feeding raw data into hazard early-warning systems (EWS), the output from which can then be disseminated in visually appealing form back to users (Paul et al., 2018). They are generally highly context (i.e. country, natural hazard)-specific: two examples are MAppERS (Mobile Applications for Emergency Response and Support), which aims to reduce flood risk in Denmark by allowing users to share geospatial data such as geotagged images of flood extent with basin authorities (Frigerio et al., 2018); and MyShake, a global seismic platform that exploits users' smartphones to detect earthquakes and record the magnitude of ground shaking (Rochford et al., 2018). Elsewhere, other apps have been developed with the specific purpose of indirectly enhancing DRR by growing the observational database, which is often too sparse to generate accurate or timely warnings or alerts (Seibert et al., 2019).

Mobile technologies have rich potential in ensuring more equitable resilience by mobilising marginalised actors who might otherwise have been bypassed by more traditional knowledge generation practices. These include people with disabilities, who are four times more likely to die when a disaster strikes; or women, who are more vulnerable in disaster situations (Craig et al., 2019). The Covid-19 pandemic has drawn the utility of mobile phones into focus as a vital communications lifeline for many vulnerable groups who are unable or unwilling to leave their residence. At the same time, such communications and mobile-generated datasets have limitations that, if insufficiently understood and accounted for, may result in analytical and ethical oversights, such as compromised privacy or degraded data quality. Especially in the realm of app development, if these concerns and user needs are not considered, long-term resilience building efforts may actually be hindered or even reversed (Crawford and Finn, 2015; Haworth et al., 2018). There are very few studies that interrogate the myriad factors that govern user perceptions of apps and social media, and by extension their trust in hazard alerts and risk information (Appleby-Arnold et al., 2019).

We therefore began from the widely accepted contention that risk communication and public engagement within the DRM life-cycle, in the broadest sense, require improvement (Umansky and Fuhrberg, 2018). Much DRR information provided to the public is too technical; such information often refers to the macro level rather than being tailored to the micro/community level; and poor disaster
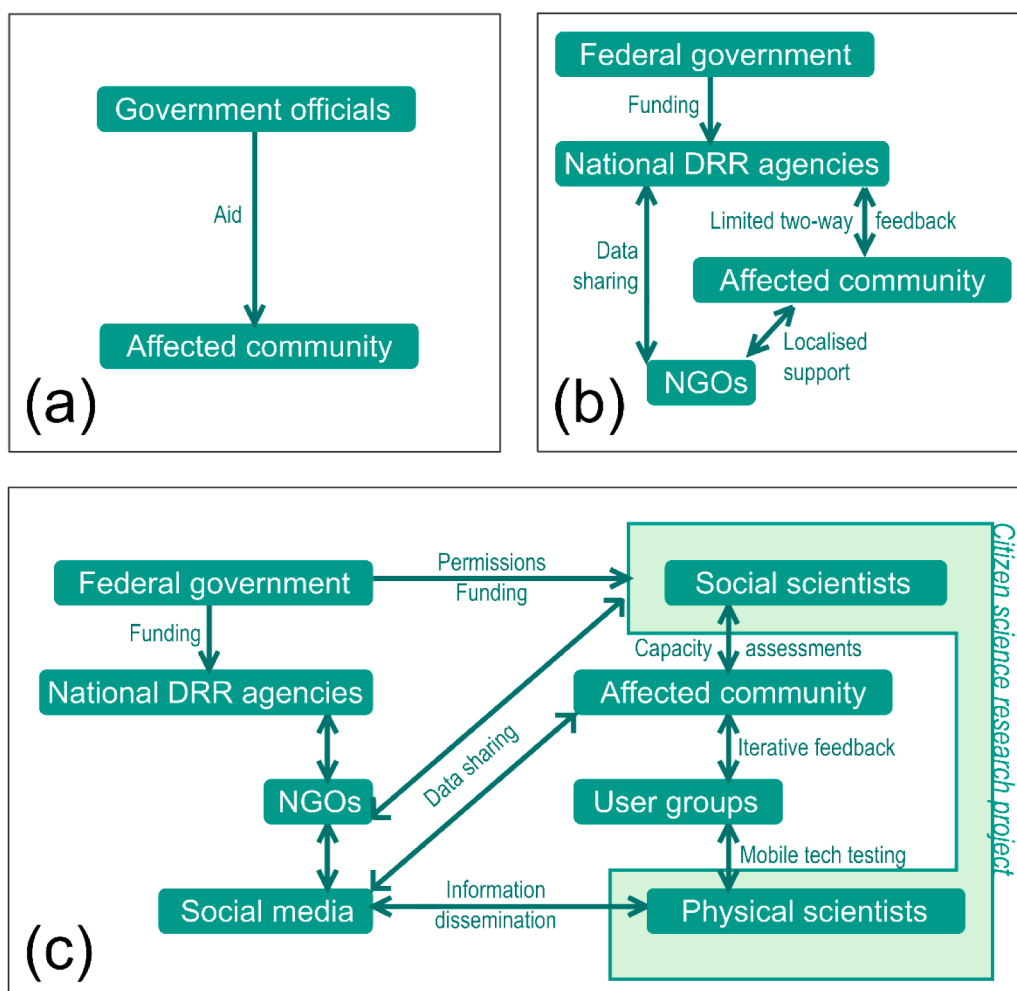

Fig. 2. Representation of information flows and governance arrangements in DRM in a developing country context for (a) formal government response only; (b) decentralised approach involving limited NGO interaction; (c) polycentric approach involving mobile phone technologies.

governance is the corollary (Paul et al., 2018). Indeed, the greatest shortcoming of EWS is that risk information regularly fails to reach people at risk (Gething and Tatem, 2011; Haworth et al., 2018). Mobile technologies can provide a remedy; yet their usage in DRR, especially in developing countries, is inconsistent and often highly compartmentalised around specific hazards.

To address these outstanding issues, we convened a one-day workshop involving 45 workers from 20 different organisations – including physical and social science public and private research bodies, technological developers, NGOs, and federal, local, and intergovernmental bodies. The educational and professional backgrounds of these workers was highly varied and included:

- Scientific experts involved in trialling new technologies – such as automatic weather stations and mobile real-time data transmission – in targeted rural communities, as well as mobile/app developers with less experience of local installations;
- Experts working more closely with such communities over long time periods to obtain direct experience of local institutions, power dynamics, and social hierarchies;
- Those involved in the short-term distribution of emergency aid, as well as the decision-makers governing (inter)national aid allocation and funding;
- Non-professional participants ("citizen scientists") in community-level initiatives involving mobile technologies in DRR efforts;
- Data visualisation and risk communication experts.

This unusual breadth of expertise allowed us to marshal key learnings and examine common challenges and opportunities where mobile technologies could usefully be harnessed in DRR through different stages of the DRM lifecycle, and across different regions. While other guidelines are typically anchored to a specific natural hazard or region, we sought to devise a new framework that is generalisable, scalable, and hazard- and location-agnostic.

2. Discussion

We first identify areas where mobile technologies have already been successfully leveraged in DRR, before exploring outstanding challenges and proposing a set of best-practice guidelines. In common with all resilience-building programmes, mobiles enable rapid and reliable dissemination of data and information, enabling a more distributed and decentralised web of conversations and information flow (Fig. 2). This sits well with a devolved, polycentric approach to DRR (Paul et al., 2018; Buytaert et al., 2016). Moreover, there is sizeable potential for the generation of new social capital by reducing the gap between different communities, and bringing together different actors (such as farmers, NGOs, and government organisations) to discuss issues relating to data collection and capacity building. However, fitting a technology or app to a particular local context is a challenging task; Internet/smartphone access is often variable and costly, which excludes some of the most vulnerable community members (such as women, those with disabilities, and the elderly), who are often the most affected by disasters. The most profound and seemingly intractable bottlenecks revolve around participation: what are the most effective strategies for user engagement that support uptake and enhance the sustainable use of a new app or platform? And how can the ethics of data collection and intellectual property rights (IPR) be accounted for? In other words, who owns the app, content, data, and generated information?

User engagement critically depends upon first identifying a target audience, or a group of people who would benefit from the introduction of a new mobile technology. Many existing apps fail to discriminate beyond a generic grouping of 'non-scientists' or 'citizens': it is important to recognise the livelihood needs and information priorities of different stakeholders a priori, which rarely

Table 1
Categorisation of DRR projects that use mobile technologies based on those leading them.

Project leader/ beneficiary	Opportunities	Challenges
Generic non-scientist/ citizen	Crowdsourcing: rapid generation of spatiotemporally dense hazard data. No requirement for behavioural change. Little impact on daily lives.	Often no tangible incentive for participating. Ethics issues e.g. sharing of private numbers. Raw data often incomplete and poor quality, requiring moderation. Potentially low impact on livelihood needs due to minimal direct engagement.
Professional physical scientist	Often small-scale, low-cost proofs-of-concept. Can result in enhanced process understanding of e.g. landslides or earthquakes. Non-resource-intensive means of obtaining and analysing new datasets. Possibility of validating existing, more sophisticated, data and numerical models.	High risk of failure; proofs-of-concept often not relevant to local disaster management; constraints of funding lifecycle preclude sustainable uptake of new technologies; negative externalities can be generated locally (e.g. diminished trust in official, government-sanctioned hazard data); insufficient user-centered design processes
Mobile technologist	Possibility for visually appealing technologies (e.g. multimedia content) that could enhance uptake. Data input, analysis, dissemination can be optimised for efficiency. Ability to harness latest technological progress e.g. off-the-shelf smartphone sensors for measuring ground shaking or volcanic gas composition.	Cannot work in isolation; will always depend heavily on physical and social scientists for context. New apps or platforms are sometimes an end in themselves, with little regard to their uptake, application, or sustainable use. Often expensive and might not be fit-for-purpose after reviewing user needs.
Targeted user group	Knowledge of usefulness of new technology and potential for high degree of initial uptake. User-centered design provides optimal solution for local relevance. No replication of existing technology. Potentially highly useful way to engage users in light of Covid-19 pandemic.	Fit-for-purpose for everyone, taking into account a spectrum of different user needs, so expensive. Requires a careful balance between cost and degree of specialisation. Sometimes technology/ science (supply) cannot satisfy user needs (demand).

align (e.g. scientists, farmers, technology developers, local and federal disaster agencies). We divide mobile technologies into four groups: those developed and led by citizens, science, technology, and targeted users (Table 1). The most obvious realisation is that people affected by a hazard must be involved in project design from the outset. In order to facilitate this process, the intrinsic involvement of social scientists is key to identify relevant actors, power and finance flows, and areas of acute local vulnerability, by conducting livelihood interviews and vulnerability and capacity assessments. Similar assessments of local mobile ownership and access of the target population would foster inclusivity and accessibility of any proposed new mobile technology, avoiding marginalising the input of those with different access needs. From a DRR perspective, careful analyses of existing indigenous environmental knowledge (and similar/overlapping local initiatives) have the potential to avoid replication, but are rarely undertaken rigorously: such knowledge is often highly qualitative, subjective, and anecdotal, and is difficult to transform into quantitative data that inform, for instance, the development of a new app.

The corollary of user engagement is motivation, which must be carefully analysed in the context of local dynamics and needs. The importance of tailoring a mobile technology for local relevance was common across all DRR projects: user motivation to participate is a direct function of proximity (or degree of knowledge, or of being affected) to a hazard, and often evolves over time. A useful way to begin is with existing technologies or apps (e.g. WhatsApp or OSM), then making adaptations to be user-driven: this 'piggybacking' technique requires fewer overheads and includes existing, known, user behaviours. In this sense, user motivation must also take into account simplicity of use, and the ease with which a new technology can be assimilated and integrated into existing daily life: many new apps have failed as they are overcomplicated, ask too much of users, or simply are never used due to other, more immediately pressing, priorities (such as subsistence farming, water collection, or raising children).

So motivation hinges on local relevance and usefulness, i.e. will the app or new technology be useful, useable, and used by the target audience. In most projects, motivation depends upon some form of incentivisation, which must also be considered. While an existing group of disaster management volunteers might already be motivated, what means exist for tapping into a wider group of citizens, given that people might already have many apps in use? In many cases, financial compensation is used to kick-start participation: for instance, direct payment based on a certain number of contributed data points or edits to a hazard map using OSM. Establishing a direct link between participation and enhanced resilience is a longer-term solution that is more difficult to implement, yet has the potential to yield more fruitful and enduring results. The establishment of local relevance is useful in this regard: if a user is able to view, for instance, the way in which their geotagged measurements of ground shaking or landslides have contributed towards a predictive model of potential earthquake damage to their home, they have a greater incentive to continue participating. Similarly, if a new app or technology were designed around the user to include visually appealing simulated formats (e.g. serious games), further incentives could be added, like a sense of competition or civic/community pride (e.g. who can contribute the most or 'best' measurements?).

User-centered design (UCD), in which users are placed at the centre of the development of a new mobile product in an iterative process, is therefore indispensable for promoting trust in, and uptake of, the product within communities. That the new product should
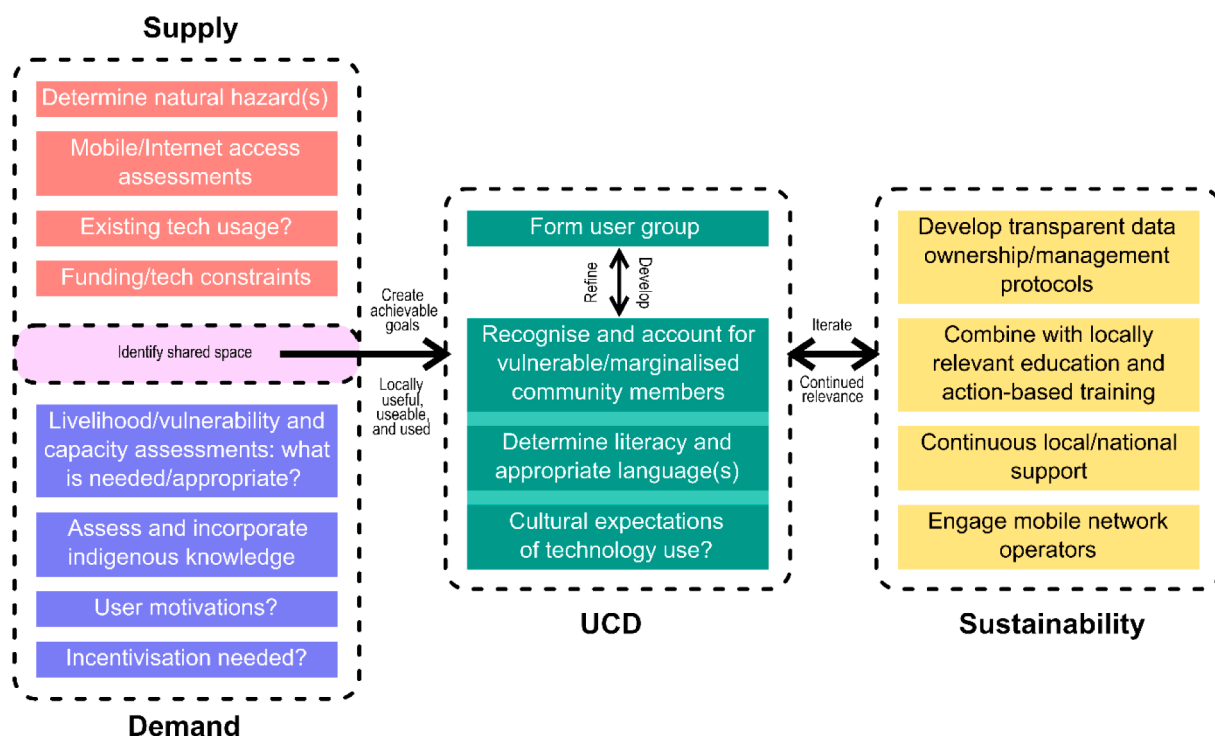

Fig. 3. Best-practice context-agnostic guidelines for mobile technology use in DRR.

be driven by successful user data entry as far as possible, using a human-centered design/co-design methodology to elicit user requirements, presents multiple challenges. First, mobile technologies (especially new apps) are useful new modalities in the DRR toolkit rather than universal panaceas, and may not be the most appropriate solution for users (e.g. from a DRM perspective, or in poorly developed rural areas specifically). Many projects do not succeed as they start from a preconceived notion that it would be 'nice to develop an app' (Pandeya et al., 2020; Paul et al., 2019). Secondly, rarely can user demand be entirely satisfied by scientific or current mobile technological supply: it is better to seek the shared space between supply and demand (Fig. 3). Thirdly, IPR and data ownership, protection, and maintenance issues may challenge UCD: keeping apps free is difficult, while engaging end-users is often beyond the capabilities or skillsets of physical scientists or app developers. However, mobile user assessments and UCD – catering to different user needs – are critical pre-requisites for accessibility. We identified four key principles that support UCD:

- Design should recognise vulnerable community members e.g. in remote areas of rural Nepal (such as the far-western development region) and India, women have less access to mobile technology despite being the subset of the population most vulnerable to the effects of disasters(Craig et al., 2019);
- Consideration should be paid to local language and literacy rates, for instance by dividing a new app into levels of different complexity;
- Different cultural expectations of the availability to use and respond to DRR information and requests via mobiles must be taken into account, e.g. differing concepts of intrusion into personal time;
- There should be a recognition that different communities use different technologies, such as social media platforms; e.g. WhatsApp and Facebook see widespread use in southeast Asia, yet Telegram is generally more popular across Africa.

Once launched, the final issue confronting the use of a new mobile technology revolves around sustainability, i.e. ensuring the continuation of uptake and usage beyond the pattern of short-term funding cycles, allowing it to achieve long-term change and a lasting direct and positive impact on DRR. One common theme is that the development and use of mobile technologies should be seen as a continuous and iterative process rather than an event: in this way, projects can build relationships and foster networks between key stakeholders, and create spaces for conversations about DRR and data collection, access, and use. Ideally, continuous professional support and funding – from either national government or a national higher education institute – should be available; though, due to funding and capacity constraints, this is rarely the case. Co-production of new technologies with users provides a means of enhancing buy-in and sustainability, while action-based training sessions and combining user engagement with education both augment local environmental awareness, which can build long-term scientific and DRR capacity while also potentially empowering marginalised communities. Engaging mobile network operators alongside end-users and federal risk management agencies could also generate different modalities to sustain the useability and usefulness of mobile technology like apps; for example, by having open-source data available for others to use and adapt in order to support distribution.

Fig. 3 presents our findings – examining best practice to understand user engagement, participation, motivation, and long-term technological usefulness and sustainability – in a new set of context-agnostic generalisable guidelines to support the use of mobile technologies in DRR efforts.

CRediT authorship contribution statement

J.D.P.: Writing, Visualization, Investigation, Methodology, Project administration. **E.B.**: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration. **M.B.**: Investigation, Methodology, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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