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Brief Communication: Inclusiveness in designing early warning system for flood resilience

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Abstract. Floods remain a wicked-problem and are becoming more destructive with widespread ecological, social and economic impacts. The problem is particularly acute in modified formerly pristine, mountainous river-catchments where plausible assumptions of risk-behaviour relevant to flood exposure and vulnerability are crucial for robust early warning system development. In particular more focused conversation with the community-at-risks is required. In such context, we advocate the use of a **SMART**-approach to facilitate bottom-up initiatives to facilitate development of inclusive and purposeful early warning systems that benefit the community-at-risk by engaging them every step of the way along with including other stakeholders at multiple-scales of operations.

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1 Introduction

The theme for World Meteorological Day 2022 (March 23) was 'Early Warning and Early Action – Hydrometeorological and Climate Information for Disaster Risk Reduction' which emphasises the vital importance of information generation and sharing to minimize the risks from hydrometeorological extremes. Further, the United Nations secretary-general announced a major initiative, to be delivered via COP 27 (UN Climate Conference), for 'everyone on Earth should be protected by early warning systems against extreme weather and climate change within the next five years.' These policy initiatives indicate the growing need for new information and knowledge relating to risks arising directly from hazard but also from the complex interactions with exposure and vulnerability (IPCC defined risk=hazard × exposure × vulnerability, see details in Cardona et al., 2012). Although our understanding of hydrological extremes, such as floods, has evolved in recent decades as we view them through the lens of hydro-complexity (Kirschke & Kosow, 2021; Kosow et al., 2022). However, floods remain a "wicked" problem and are becoming more destructive with ecological, social and economic impacts (i.e., source of water pollution, damages to wastewater and irrigation system, excessive erosion damaging riverbank settlements, see details in Kosow et al., 2022; Hannah et al., 2020). In mountainous regions floods are becoming more unpredictable and destructive in response to increasing climatic extremes. This is exacerbated by anthropogenic pressures which have severely modified formerly pristine, high altitude river catchments. Furthermore, increased encroachment of riverbanks, dumping of solid and sewer waste and rapid urbanisation has increased the proportion of low-income communities living in flood-prone areas (Mao et al., 2018; Paul et., al., 2018). The lack of adequate hydrometeorological monitoring networks or early warning system in these regions causes undue damage to live and property (Mountain-EVO, 2017; Pandeya et al., 2021). Yet prediction of risks associated with floods is difficult to achieve in such data-scarce mountainous regions.

Indeed, the most recent report of the Intergovernmental Panel on Climate Change (IPCC, 2022) highlighted the urgent need for investment in adaptation and resilience, particularly in developing regions which have been historically underfunding but are already impacted by extreme weather events. A key requirement is to improve early warning alerts of anticipated storms, heatwaves, floods and droughts. To generate such warning information for floods, systematic development of monitoring networks that utilise appropriate technologies are required. These systems should as also consider social, cultural and political dimensions to ensure responses following appropriate decision-making chains (Mao et al., 2018; Acosta-Coll et al., 2018). Such an integrated and interconnected monitoring system requires science, policy and local community-led approaches that can bring engaged stakeholders together and generate knowledge to guide their decision to propose solutions that fit the local context (Buytaert et al., 2018; Kosow et al., 2022; Roque et al., 2021; Zulkafli et al., 2017). Despite this call for an inclusive approach for generating early warning alert system, the existing flood monitoring practices and designs are strongly technology-driven (i.e., information and communications technology [ICT]) and focus less on converging local socio-cultural and governance context (Mao et al., 2018; Westerhoff et al., 2021). There are still questions on how, where and at what level science, policy and society may converge and facilitate bottom-up initiatives for decision-making and develop innovative solutions to address challenges posed by floods.

In this commentary, we assess potential approaches for facilitating inclusiveness in the design of flood early warning system by integrating social, cultural and political aspects, and identify preconditions and missing links.

2 Current approaches to facilitates inclusiveness in water and disaster research

In water and disaster research several approaches are emerging to provide concepts, tools and framings that can be used to support inclusiveness and disciplinary convergence for actionable knowledge production. The concept of knowledge co-production has emerged from science-society interaction under the umbrella of adaptive governance thinking where polycentric models and power relation received attention (see details in Buytaert et al., 2018; Paul et al., 2018 and Zulkafli et al., 2017). Scholarly research has identified several potential approaches to achieve knowledge co-production under the broader umbrella of the participatory action research (PAR) including participatory modelling (Sterling et al., 2019), community-based participatory approaches (Wallerstein et al., 2017), participatory scenario analysis (Birthisel et al., 2020; Lakhina et al., 2021; Westerhoff et al., 2021), among others. More recently, citizen science has emerged and emphasises on

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"knowledge creation" with limited focus on action and development but more on new technologies, especially ICT. In addition, citizen science focuses more on participation by volunteers, developing trust and nurturing existing working relation among involved actors towards knowledge co-production (Buytaert et al., 2018; Zulkafli et al., 2017).

In the contemporary disaster research literature, knowledge co-production is advocated along with participatory actions and transdisciplinary research, which laid the foundation for the participatory convergence concept to translate research into practice (Lakhina et al., 2021; Peek et al., 2020; Roque et al., 2021). Peek et al. (2020) define the participatory convergence research as 'an approach to knowledge production and action that involves diverse teams working together in novel ways—transcending disciplinary and organizational boundaries—to address vexing social, economic, environmental, and technical challenges in an effort to reduce disaster losses and promote collective well-being' (pp. 2). While this research approach has been identified as one of the best ten big ideas in funding allocation and research direction by the National Science Foundation of USA (2016), there has been little exploration on the framing (i.e., methods and ethics) to apply this in practice (Westerhoff et al., 2021). Indeed, scholars are focusing on more empirical exploration of convergence research to generate ethics and methods that may deliver successful outcomes. For example, research attempting to address coping with water extremes such as floods and droughts (Lakhina et al., 2021, Roque et al., 2021; Westerhoff et al., 2021). Recently scholars have proposed ethics that have proven useful. For example, Lakhina et al., (2021) proposed 'convergence with CARE: collaboration, accountability, responsiveness and empowerment' which require community engagement and further highlight their perspective, questions and experiences while disregarding traditional hierarchical approaches. However, much of hydrological research is focused on improving scientific measurements and developing technological solutions. For example, improving model uncertainty or the instruments and networks used to measure different facets of the hydrosphere (Beven et al., 2020) while being useful for advancing the discipline result in solutions that are often difficult to disseminate to local communities (Birthisel et al., 2020; Roque et al., 2021; Westerhoff et al., 2021). Earlier reviews indicate many empirical investigations on how social context, such as culture, politics and economics have shaped water knowledge and how and what interventions influence or shape communities' respond differently (Roque et al., 2021). This emphasises a need for future research to understand the underlying principles and ethics that would facilitate bottom-up driven activities or active participation of engaged stakeholders for knowledge co-production to responds and reshape convergence research methods.

3 Processes and preconditions in early warning system development

A synthesis of the literature on flood early warning systems was reviewed to develop a schematic representation of an idealised framework for developing an inclusive early warning system (Figure 1) (for more details see Acosta-Coll et al., 2018; Buytaert et al., 2018; Mashi et. al., 2020; Paul et al., 2018; Zulkafli et al., 2017). The foundation of this schematic representation (Figure 1) is adapted from the concept of knowledge co-generation processes (Buytaert et al., 2018) and co-design framing for environmental decision-making processes in a polycentric system (Zulkafli et al., 2017) and then applied with the key elements (i.e., risk knowledge; technical monitoring and warning service; communication and dissemination of warnings and community response capability (ISDR, 2020) identified by the World Meteorological Organization, International Strategy for Disaster Reduction (ISDR). All these concepts, in general advocated participatory and citizen science approach to become inclusive and generate actionable knowledge (Buytaert et al., 2018; ISDR, 2020; Paul et al., 2018; WMO, 2020). The disaster risk equation provided by the IPCC ($risk = hazard \times exposure \times vulnerability \div capacity\ to\ cope$) suggest that reduction in risk is dependent not only on efficient forecasting of hazard, but also on the understanding of associated exposure, vulnerability and capacity to cope by the exposed community. Therefore, in Figure 1, we present three interdependent steps, i.e., collate data on risk generate data and models to facilitate forecasting and disseminate that is necessary to develop a system that not only produce flood alerts, but also provide risks information through monitoring exposure, vulnerability and capacity of the community-at-risk.

3.1 Mapping the risks through data collection and observation

In this step, it is crucial to collect as much information possible, to generate knowledge on the locality and the community at risk to design a purposeful early warning system. The knowledge generated can also inform on exposure, vulnerability and ability to cope if a disaster strikes and enables decision-makers to adjust or adapt necessary precautionary measures to respond efficiently in a timely manner (Buytaert et al., 2018; Pandeya et al., 2020). The required knowledge includes scientific measurements of the hydrological hazard, various context of risks information (i.e., vulnerability and exposure mapping) across the socio, cultural and political domains that contribute to the risk portfolio to be more intense and having long-term consequences (Mao et al., 2018). In general, we found most studies generate information on risk through a baseline survey of exposure and vulnerability analysis vis observation, interviews, focus group discussions, stakeholders' meetings. The data focuses on a variety of aspects including historical analysis, geographical aspects, environmental, social, economic and governance structures. All these are relevant, however, what is missing here is the lens through which it is possible to explore the complexity of the risk portfolio determined through different angles of exposure and vulnerability perceived by different stakeholders. Reaction to risks in terms of exposure and vulnerability are dependent on the social, cultural and political stances of stakeholders, and thus is highly variable (Mashi et al., 2020). For instance, the communities that are living in flood vulnerable areas might not have legal rights to do so therefore, they might decide to tolerate that risk due to fear of eviction. Other stakeholders may be from state organisations which are not bound to provide services to this illegal settlement and therefore, will not engage. People might not engage also as they already lost their trust on the governance system (i.e., did not receive compensation for their previous flood damage, recurring failed commitments from the political parties to reduce flood vulnerability). Previous research partly discussed these complexities (e.g., Acosta-Coll et al., 2018; Mashi et al., 2020) however, solutions to these challenges are limited.

[Figure 1]

The citizen science approach, in such cases, recommend utilising social capital tools, such as building a relationship with trust across stakeholders, identifying the people with leadership qualities or local champions (i.e., community members or a social activist/government/non-government employee who have some form of knowledge of flood risks and keen to learn about the early warning system) (Acosta-Coll et al., 2018; Mashi et al., 2020). Previous research and project experiences in a similar context demonstrated conducting structured dialogue through stakeholders' meetings, focus group discussions and forming of community groups (see further details in Acosta-Coll et al., 2018; Mashi et. al., 2020). However, these interactions can lead to confusion and unrealistic expectation relating to the monitoring system. Therefore, it is crucial to make plausible assumptions of risk behaviour relevant to flood exposure and vulnerability that can feed into designing the early warning system including having more focused conversation with the community at risks, specifying the aim and expected outcome of the flood monitoring system.

3.2 Forecasting hazard risks and establish an alert system in real time

This step utilises information from the previous step to identify design specifications to build the early warning system. For example, suitable sensor technology, identification of relevant variables (i.e., rainfall, water level), suitable location(s) to install the components and transmit/receive data. In addition, decision-making on data collection attributes, such as data transmission frequency, among others is critical because there will always be a trade-off between lead time and the potential for an early warning to facilitate appropriate community responses to reduce the likelihood of life. Thus, an understanding of what the optimal lead time in a certain context should be is crucial. To enable any data processing activity, adequate monitoring of relevant variables must be undertaken at the relevant spatial and temporal resolution or scale. This scale will vary depending on the topographic complexity, landcover, geology and hydrodynamic properties of the catchment of interest (Lauden and Sponseller 2018). If historical data is limited (often the case with mountainous and logistically challenging environments) a period of baseline data collection through the previous step is required to "get to your catchment" before establishing a monitoring network. A range of analytical tools are available, including, statistical modelling and simulation, to provide robust thresholds to trigger alert levels based on the collected

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data. This forecasting step – i.e., predicting the likelihood of flood based on antecedent conditions - is a challenge in data-scarce regions like the Himalaya where there may be significant uncertainty associated with any alert/alarm thresholds due to insufficient training data (Mountain-EVO, 2017; Pandeya et al., 2019). Therefore, many risk assumptions are involved in this step such as over-promising for a sensor-based alert system and if the forecasts are not accurate, there may be a resentment in the community regarding the project. This raises an important question relating to understanding the local context to get a good understanding on how risk management happens and what this means for the design? Moreover, how and when to involve the community (non-scientists) in the development process? Also, what is the purpose of involving the community and other organisations and how will their involvement shape the design process?

Previous research has highlighted the importance of involving relevant state organisations, such as disaster management departments or meteorological organisations at this stage (Acosta-Coll et al., 2018; Pandeya et al., 2019). However, this can potentially lead to a divergence in terms of priorities; scientist and engineers are generally focused on the success of the adopted technique and necessary data generation, while the state-led organisations might focus on bureaucracy, policy, existing government beliefs and long-term operational plans (e.g., maintenance and legacy costs). Therefore, engaging with the state departments at this stage can become very difficult (Mashi et al., 2020), nonetheless from a design perspective, understanding both contexts are very crucial for building a purposeful early warning system. The previous researcher recommended utilising a bridging or boundary organisation that can act as a mediator and bridge the gap (Acosta-Coll et al., 2018; Mashi et. al., 2020). Few projects involved local technological start-up companies or local research and development organisations. However, there is limited exploration on the community engagement at this stage who struggle to visualise such technical details in real-time application. Further, there are also missing on the crucial aspects of what levels of technical details to share and which is the right time/phase to share with the community or the state authority. This inadequate understanding to decide the right time or phase will risk of over-promising for warning alert.

3.3 Communication and dissemination

After installation of the alert system, identification of the best possible modes of dissemination is critical to further interact with the vulnerable communities and communicate the potential risks along with tentative necessary actions to minimise the risks. While this has been the most critical part, it is also one of the most interactive components in the entire scheme. New ICT technologies such as interactive dashboard visualisations, give more flexibility in developing the visualisation to disseminate the EWS outputs in a way that can be easily understood by the community is a major challenge (Mashi et al., 2020; Pandeya et al., 2019). Several questions arise in this step including a strategy to ensure the alert levels reaches to all those who are at risk, the risk information is easy to understand and there is a desired reaction to such information. Previous research highlights different visualisation techniques to showcase alert levels such as text, colour coding, graphics, audio mobile messages, and showcasing locational maps (Acosta-Coll et al., 2018; Pandeya et al., 2019). What may be missing in this step is what would be the best possible methods to communicate with the community at risk and understanding how they perceived and responded to such forms of alerts or warnings? Here, communication not only with the communities but also with the responsible state authorities and how they are supporting or involving with the decision-making processes to respond in a timely manner.

4 A SMART way to forward

We believe that through this commentary we have raised critical questions and identified missing links that need deeper exploration to ensure inclusive EWS are developed in data-scarce mountainous regions or geographic regions similar in context. Multiple lenses are required to establish and explore the complexity of the risk portfolio and to understand the architecture of the engaged stakeholders and their behaviour in generating actionable knowledge and strengthening bottom-up initiatives to respond and improve capacity. Based on the above discussions on the key questions and design needs, we propose the '**SMART** convergence participatory research' approach as a checklist of good practices with greater promise in this context. We highlight crucial steps for multi-disciplinary team to follow when exploring risk architectures and planning response actions

(Figure 2). These include: **S**hared understanding of the risks (i.e., developing a risk portfolio to map out risks factors through exposure and vulnerability analysis and associated actors, identify common goals), **M**onitoring of the risk through knowledge co-production and collaboration (i.e., trust-building, providing feedbacks, forming small groups), building **A**wareness (i.e., training and capacity development activities) and pre-plan **R**esponse action on **T**ime (i.e., comprehensive disaster management plan, evacuation plan).

[Figure 2]

We advocate the use of the **SMART** approach to facilitate bottom-up initiatives for developing an inclusive and purposeful early warning system that would benefit the community at risk by engaging them every step of the way along with including other stakeholders at multiple scales of operations (i.e., scientific and policy actors). Broadly, this **SMART** convergence approach along with the dominant largely top-down initiatives will contribute to developing capacity and redefining adaptation and resilience in the face of increased hydrological uncertainty.

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Figures (1& 2)

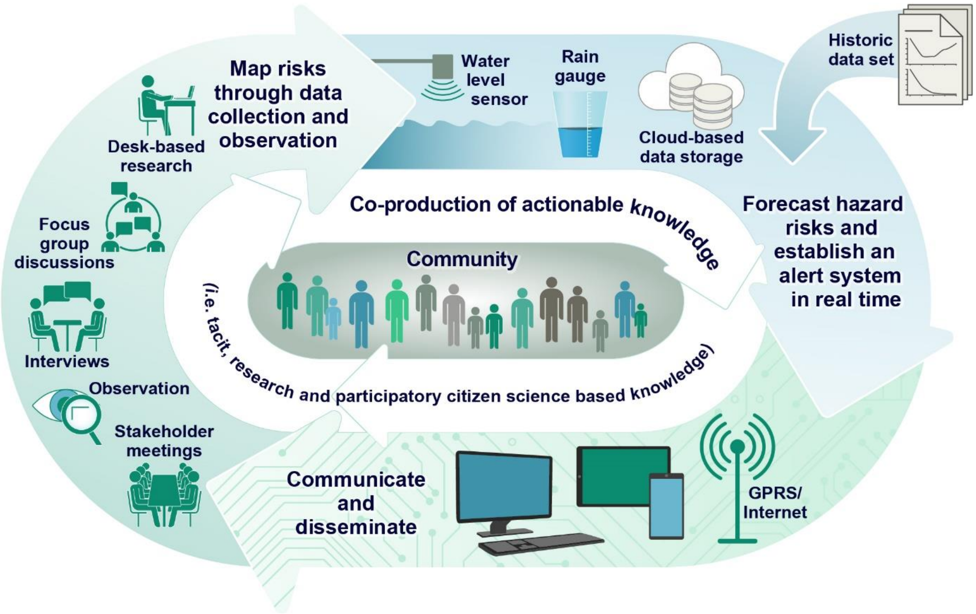

Figure 1: An idealised scenario for developing a monitoring and alert system to provide an early warning of potentially life/livelihood threatening natural disasters.

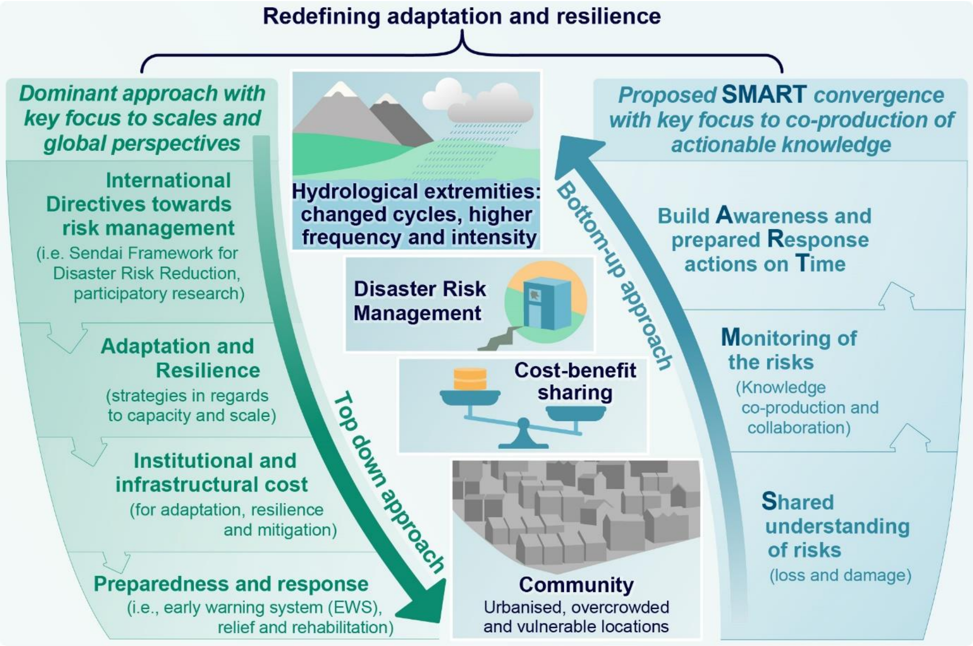

*Figure 2: A **SMART** convergence research approach to ensure inclusiveness in disaster risk management*

Authors contribution

TY and DMH prepared the manuscript with contributions from all co-authors.

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Useful links and report links

1. Mountain-EVO (2017) project paper and reports are available at: paramo.cc.ic.ac.uk/espa/
2. International Strategy for Disaster Reduction (ISDR). Emerging Challenges for Early Warning Systems in context of Climate Change and Urbanization. Available online: http://www.preventionweb.net/files/15689_ewsincontextofccandurbanization.pdf
3. Guidelines on Early Warning Systems and Application of Nowcasting and Warning Operations (2010) by World Meteorological Organization (p. 25) and can be access through https://library.wmo.int/doc_num.php?explnum_id=9456

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