Environmental Development xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Environmental Development

journal homepage: www.elsevier.com/locate/envdev

When the river talks to its people: Local knowledge-based flood forecasting in Gandak River basin, India

Amitangshu Acharya[a,*], Anjal Prakash[b]

[a] Research Institute of Geography and the Lived Environment, School of GeoSciences, University of Edinburgh, UK
[b] HI AWARE, International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal

ARTICLE INFO

Keywords:
Flood forecasting
Early warning
Local knowledge
Gender
Transboundary water
Gandak River
Bihar
India

ABSTRACT

Local knowledge on flood forecasting and meteorological phenomenon have received scant research attention in South Asia. While local communities are often recognised as key producers of knowledge on adaptation and resilience, their role as producers of knowledge of meteorology and flood forecasting has drawn lesser interest than their consumption of it as end users. Moreover, the opinion that has carried through to limited research on this issue has been largely that of men. This paper attempts to address such a research gap, by recording various sophisticated means deployed by local communities living in villages in transboundary Gandak River basin in Bihar, India, to forecast floods and heavy rainfall. This research documents the gendered process by which local knowledge is produced through complex interaction between fine-grained observations and official early warning systems. It also explores how communities practice knowledge innovation by making generic and centralized flood forecasting information locally applicable, through triangulation. Our research argues that 'local' should not be recognised purely for dissemination of flood early warning information but also as a place of knowledge generation on flood forecasting. Current discourse on flood forecasting needs to recognize the gendered production of meteorological and flood forecasting knowledge in local communities. Furthermore, strengthening local knowledge systems on flood forecasting can work to counterbalance the drawbacks of centralized flood early warning systems, provided gender concerns embedded in both are recognised. Based on field research, this paper concludes that production and consumption of flood forecasting knowledge needs local and scientific communities to work together for reducing knowledge gaps at both ends.

1. Introduction

South Asia is one of the most flood-affected regions in the world. In 2010, almost 45 million people were considered to be exposed to flooding, which accounted for almost 65% of the total global flood exposed population for that year (UNISDR, 2011). The 2017 flood in South Asia affected 41 million people in Bangladesh, India, Nepal and Pakistan (Ferand, 2017).[1] Globally, Bangladesh and India are the two most flood-prone countries, with 40 million hectares of land prone to flooding in India alone (Singh and Kumar, 2013). Floods have been estimated to have affected the lives of 33 million people in India between 1953 and 2000 (Mohapatra and

* Corresponding author.
E-mail address: amitangshu.acharya@ed.ac.uk (A. Acharya).

[1] Ferand, Chloe INDEPENDENT: "At least 41 million people affected in floods in India, Bangladesh and Nepal, UN says", August 30, 2017. Accessed September 12, 2017. Accessed at https://www.independent.co.uk/news/world/asia/india-floods-bangladesh-nepal-millions-affected-says-un-a7920721.html [Date of Access – May 23, 2018].

https://doi.org/10.1016/j.envdev.2018.12.003
Received 16 July 2018; Accepted 6 December 2018
2211-4645/

Singh, 2003). Moreover, between 1978 and 2006, 2443 flood events occurred in India, which claimed the lives of 44,951 people (Singh and Kumar, 2013). Most of the rivers and numerous tributaries in South Asia originates in the Hindu-Kush Himalayan (HKH) region. A 30-year (1973–2002) trend analysis of available data of major flood events in South Asia concluded that the trend is increasing (Dutta and Herath, 2004). Recent studies, using a cryospheric-hydrological model, illustrate an upsurge in the magnitude of climatic means and extremes in future in HKH region (Wijngaard et al., 2017). This has lent further credence to prediction of future hydrological extremes, such as floods, which may bring grave threats for people living in the three major river basins - the Indus, Ganges and Brahmaputra (Wijngaard et al., 2017). The extreme events mentioned above have also been attributed global warming (Hirabayashi et al., 2013)

Given the recurrence of floods and the scale of its impact, scholars, and activists have often articulated the need for engaging closely with communities and their knowledge systems to inform flood adaptation strategies (Parker and Handmer, 1998; Mishra, 2001; Kelman et al., 2012). The UN Yokohama Strategy and Plan of Action for a Safer World asked for all countries to “Aim at the application of traditional knowledge, practices and values of local communities for disaster reduction (DHA,1994:14).

Though such policy support has pressed for recognition of local communities as contributors of knowledge on adaptation and resilience, yet, their role as producers of knowledge has drawn lesser interest than their consumption of it (UNEP-GEAS, 2012). Flood research in South Asia mostly focus on management of hazards and vulnerabilities by providing structural solutions such as embankments and reservoirs. Though some scholars have argued that vulnerability of communities in risk-prone areas must be addressed by improving resilience capability (Dixit et al., 2003), research on resilience and adaptation has prioritized investigation of impacts of disasters on people and how they adapt to it (Xenariosa et al., 2017), rather than how they can predict their onset. Gladfelter (2018), in her research on community-based early warning systems in the Karnali River Basin, Nepal, states that local communities did attempt to predict floods using ecological indicators, but did not find it to be very reliable. However, research on local knowledge of disasters in South Asia, though limited, suggest, to the contrary, a highly sophisticated knowledge system of forecasting floods and extreme weather events which local communities believe to be more dependable than official early warning systems (Schware, 1982, 1984; Dekens, 2007a, 2007b; Santha et al., 2014). Concerns around the inability of centralized official early warning systems to generate and distribute dependable data, has led scholars to argue for deeper engagement with local knowledge systems to compensate for the pitfalls of the former (Schware, 1982, 1984).

This paper examines gendered construction of local flood forecasting knowledge of rural communities in India living in the Gandak River basin – a transboundary river that originates in China and flows through Nepal and India (Dandekhya et al., 2017). Based on an exploratory research, we argue that local knowledge of flood forecasting in the study area has not only developed through years of fine-grained observations, but it is also flexible and iterative. It has even accommodated sparse information made available from official early warning systems in an attempt to increase its robustness. For decades, radio has been the only technology through which official early warning messages reached study sites. As our study shows, this has shaped the gendered production of local knowledge systems, where this information is being used alongside other indicators. The triangulation of flood forecasting knowledge has not been reported in scholarship on local knowledge and disasters. It shows that such aspects need further engagement and understanding, especially since socio-technological changes are taking place in the light of rising climate-related uncertainties in the region, as a warmer climate is predicted to increase the frequency and size of flooding in South Asia (Mirza, 2011; Lutz et al., 2018).

This paper is organized in four sections. Section 1 reviews the scholarship on flood early warning and local knowledge of floods and other meteorological events in South Asia, in light of increasing recurrence of floods in Himalayan rivers. Section 2 focusses on the study area in downstream of Gandak river basin in Bihar and field locations. It also explains the methodology of this study and how this study used gender disaggregated focus groups at a habitation level to generate gender differentiated granular data. Section 3 presents the main findings of this study – where we categorise different forms of indicators for forecasting flood and related meteorological events and discuss how local knowledge has evolved to accommodate official early warning information to improve robustness of prediction. In the final section we advocate for a more pluralistic engagement with flood forecasting knowledge, arguing that acknowledging local knowledge systems, and their gendered nuances, will not only counterpoise the drawbacks of centralized early flood warning systems, it will create new opportunities for knowledge co-creation.

2. Status of local knowledge of flood and meteorological forecasting in South Asia

Given the recurrence of floods in India and South Asia, and its increasing impact on the lives of the people, local knowledge of flood early warning, has drawn limited research attention, especially given the concerns around official early warning systems which has been critiqued for their ineffectiveness (Schware, 1984; Santha et al., 2014). The National Disaster Management Authority, India claims that the flood forecasting model compute real-time hydrological and hydro-meteorological data from the Central Water Commission's (CWC) flood forecasting stations to predict flood events (NDMA, 2008). Researchers have pointed out that the two key assumptions used in a number of real-time flood forecasting models in India are uniform rainfall across a river basin and catchment homogeneity (Perumal and Bhabagrahi, 2007). The length of Indian rivers and their transboundary nature has made it difficult for such methods of forecasting to generate information granular enough to be useful. For example, rainfall data was collected at upstream, where water is impounded, but rainfall and heavy monsoon squalls downstream, which amplified flood-related risk, was not monitored or factored into flood early warning calculations (Schware, 1984). Therefore, the official system was often unable to predict the possibility of causing an actual flood event downstream due to sudden reservoir discharge. At the user end, flood early warnings are communicated in quantitative volumetric terms – i.e., the quantum of water released from the reservoir in cusecs[2] (Singh et al., 2009). For the end user, it does not provide any clear idea of the geographical reach and spread of flood water, neither can it effectively indicate its intensity (Schware, 1982, 1984).

In such a context, knowledge developed through living in floodplains and surviving floods has proved to be more dependable for local communities. Unfortunately, such knowledge has been unacknowledged by official flood early warning science (UN-ESCAP, 2016). Some scholars have theoretically conceptualized such forms of rejection as "cognitive apartheid" – a form of knowledge discrimination legitimized in a society where 'textual' knowledge is valued over lived experience (Ghosh, 2016). Some of the earlier work on local knowledge of people inhabiting the catchment of the Subarnarekha River in eastern India has highlighted how forecasting severe weather condition or floods was possible because of "environmental cues, farming calendars, cropping sequences, traditional proverbs and customs" (Schware, 1984:61). Abrupt swell in mosquito and gnat populations, ants moving away from river banks and climbing up trees and buildings, the constant howling of wood cats and the flying of bats in large groups were 'environmental cues" to the local population of an impending flood (Schware, 1984:61). Research on local knowledge of disasters amongst indigenous groups in the Chittagong Hill Tracts (CHT) of Bangladesh resonate with similar findings (Irfanullah and Motaleb, 2011). Local communities in CHT use several environmental cues to forecast floods, heavy rainfall, cyclones, and other disasters. The authors categorise these examples under two broad umbrellas, 'hydro-meteorological' and 'biological' (Irfanullah and Motaleb, 2011:85). Under hydro-meteorological, they document "clouds roaring like the sea" as indicative of cyclones, while "very strong winds for 3–4 days" indicate onset of floods (Irfanullah and Motaleb, 2011:85). Under biological, the authors document that local community view the unexpected arrival of wild boar and cock in the village from upstream areas as symbolic of a looming flash flood. The behaviour of ants are often used to predict diverse types of disasters. If the ants climb up houses in a line, local communities predict a hailstorm. However, cyclones or thunderstorms *(kalboisakhi)* are predicted if they cross the road in a straight line. If they show both the behaviours, then heavy rainfall resulting in flood is predicted. Similarly, research on forecasting of weather by tribal communities in the Northeastern state of Tripura in India, list a range of biological indicators for extreme hydrological events, including floods (Acharya, 2011). This includes wilting of the petals of the flower *Cassia Tora* L., the sudden growth of ferns and moss near ditches and rivers and wasps building nests on higher ground (Acharya, 2011).

Some of the abovementioned arguments echo in Deken's (2007a, 2007b) research on local knowledge of disaster preparedness, especially related to floods and flash floods in eastern Terai of Nepal. Indicators used to predict floods are grouped under categories, such as visual (i.e., floating wood, snakes, and other dead animals; water turning muddy); auditory (i.e., **the** sound of water like that of a speeding bus) and olfactory (i.e., change in the smell of water). Dekens (2007b) also explores the role of proverbs, poems and songs in ensuring intergenerational transmission of knowledge and experience of floods. Language as a critical element in understanding and predicting disasters has been brought out in the research on local knowledge on floods conducted in the floodplains of Jamuna River in Bangladesh (Paul, 1984; Paul and Routray, 2010). Research in Bangladesh draws a clear difference between 'barsha' and 'bonna,' where inhabitants use 'barsha' to define a usual flood event, which does not reach homestead plot and helps in a good harvest of paddy (Paul, 1984; Alam, 1990). 'Bonna' explains an abnormal flood by the destruction it causes to both lives and livelihoods (Paul, 1984; Alam, 1990).

The role of the local lexicon in shaping and communicating local knowledge on disasters is also investigated by Santha et al. (2014:281) amongst coastal fish workers in Kerala, India. By unpacking "kolu" – which is an all-inclusive term used by fish workers to define an all-natural phenomenon that links to each other to become a coastal hazard – the authors tease out diverse knowledge domains. Santha et al. (2014) name the spheres as: biotic, oceanic, atmospheric, and celestial. This classification is close to that of Irfanullah and Motaleb's (2011:85) 'hydro-meteorological' and 'biological' categories but provides better space to accommodate cultural and phenomenological practices.

Though limited, scholarship on local knowledge of forecasting floods and other extreme weather events in South Asia has enabled a rich understanding of the importance of the same. However, there are several concerns about how such knowledge systems fit into official early warning systems in the subcontinent. While some researchers argue for engaging and unpacking local knowledge systems to improve official early warning systems (Schware, 1982, 1984; Paul, 1984; Paul and Routray, 2010; Acharya, 2011; Irfanullah and Motaleb, 2011), others have pointed to the problems of pursuing an instrumental agenda, arguing that local knowledge should be valued *as is*, and how local communities judge its effectiveness, instead of judging it against homogenizing narratives of mainstream scientific knowledge and official early warning systems (Dekens, 2007b; Santha et al., 2014). However, there is common ground as both groups argue for the need to acknowledge marginalized communities as producers of knowledge and strengthening local knowledge systems. But the conflict between these two schools of thought has largely remained unresolved.

A complex calculus of caste, class, and gender in South Asia shapes the production of knowledge. However, except for Dekens (2007a, 2007b), most of the scholarship on flood forecasting in South Asia do not engage with gendered aspects of local knowledge. In fact, deliberations on gender originate and ends at the point of vulnerability and divergent coping strategies for women (Xenariosa et al., 2017). But the gendered production of predictive knowledge of floods gets shelved on the research agenda. Though researchers are alert to gender issues in the field area, the voice that finally carries over is that of the men. And though Dekens (2007a, 2007b) talks about gendered methods to engaging with local knowledge, the focus shifts to gendered aspects of knowledge related to adapting to floods and not that of predicting floods. Recent research in flood-affected areas in Pakistan shows how present early warning systems are gender insensitive in their spread and communication, and how it intensifies vulnerability during flood events and argues in favour of "tailoring risk messages more effectively for different gendered contexts" (Mustafa et al., 2015: 328). Though

[2] A unit of flow (especially of water) equal to one cubic foot per second.

Fig. 1. Flood affected districts of Bihar. Map Source: BMTPC India and UNDP, Data/information compiled by Ministry of Urban Development and Poverty Alleviation. Disclaimer: ICIMOD has not verified the information of the map.

these point of views help broaden a gendered consideration of risk communication, gendered production of local knowledge of early warning systems need further investigation. Moreover, there is a concern in scholarship on the isolation of many communities from the official warning systems because of their position in the local architecture of power and privilege (Schware, 1984). Such discussions shape our research methods, as we engage with concerns on exclusion and gender in the study site. We argue that gender and caste disaggregated data collection not only brings nuance to local knowledge research in South Asia, it also allows researchers to engage with concerns of knowledge exclusion within communities.

3. Location of the study and methods

Floods in Bihar (especially North Bihar) have been produced through a complex entanglement of land revenue politics, built infrastructure (especially embankments and upstream hydrological barriers), flawed colonial and post-colonial flood policies and geomorphology of silt-bearing Himalayan rivers (Mishra, 1997; Singh, 2008). Resultantly, Bihar – considered as one of the poorest states in India, with historical and continued high poverty, unequal land distribution and upper caste dominance and caste conflicts (Rouyer, 1994) – floods have amplified existing social vulnerabilities. Several Himalayan rivers, with their catchment in Nepal, drain the plains of Bihar making it the most flood-prone state in India, with 76 per cent of the state population living in flood risk areas, and 73% of the total land area being flood affected (see Fig. 1). For the present study, West Champaran, the northernmost district in the state of Bihar, located on the Gandak river basin, was selected as the main study site. The Government of Bihar notifies West Champaran as one of the 28 flood-affected districts in the state (GoB, 2013). The reason for this selection was due to the frequent occurrence of floods in the area due to Gandak River that flows through the district. West Champaran is a rural district, accounting for 90% rural and 10% urban (GoB, 2013).

Nautan block was selected in the Gandak river basin, as it was listed as "High" out of the 18 blocks listed in the District in the HVCA – (Hazard, Vulnerability and Capacity Assessment) Report for West Champaran prepared by the Government of Bihar (GoB, 2013).

Nautan block is further constituted by 20 g Panchayats[3] (Census, 2011), of which 10 are officially listed at flood affected (GoB, 2013). After in-depth discussions with the locally elected legislatures, two of the most flood-affected Gram Panchayat and most socio-economic diverse tolas were identified in the Nautan block. Based on that, Shyampur Kotraha and Dakshin Telua were selected (See Fig. 2).

Six habitations (locally known as *tola*), (three in each Gram Panchayat for equal weight) were selected through local consultations within these two Gram Panchayats. For the final selection of the six data collection sites, local key informants were asked (a) which

[3] A gram panchayat (village council) is the only grassroots-level of Panchayati Raj, i.e; formalized local self-governance system in India at the village or small-town level.

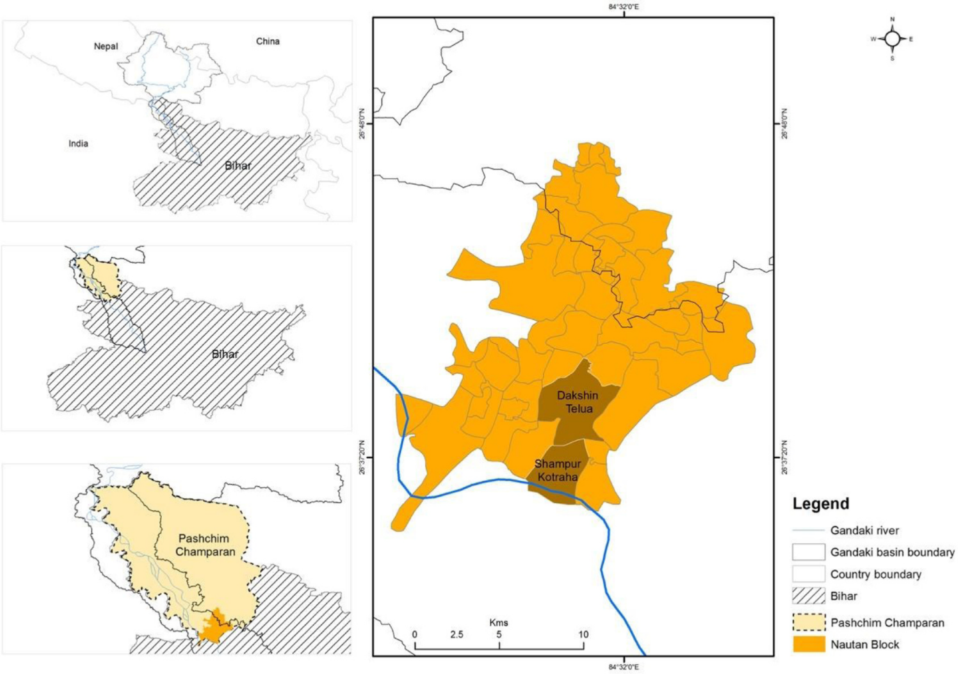

Fig. 2. Administrative Map of Nautan Block and Gram Panchayats of Dakshin Telua and Shampur Kotraha.
Source: ICIMOD.

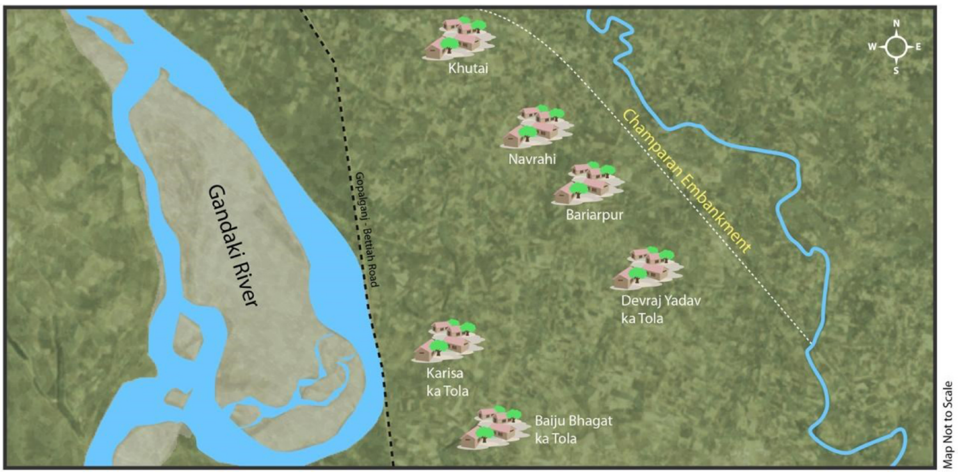

Fig. 3. Map of data collection sites, Nautan Block, West Champaran, Bihar.

habitations were located inside[4] the embankment, (b) the intensity and regularity of floods affecting them and (3) socio-economic diversity and presence of village elders, both men and women. Priority for data collection was given to villages inside embankments as they are more exposed to floods than those outside the embankment (see Fig. 3). Data were collected in two phases, one in the month of February, and second in the phase of March and April in 2016. The selection of six habitations helped to ensure the inclusion of different caste groups – namely Dalits, Muslims, Upper Castes/General Category and Other Backward Caste (OBC) (Fig. 3 and Table 1).

Qualitative methods were used for data collection, namely key informant interviews, and gender disaggregated focus group discussions. Key informants were selected for knowledge of the study area, institutional response and local communities experience of floods, flood history and local warning systems, all of which would be difficult to access distinctly through group discussions. These

[4] By 'inside', what is indicated is that these tolas (i.e. habitations) are located between the river and the embankment. Villages, which are located behind the embankment and hence protected by it, are known to be 'outside' the embankment.

Table 1
No of households and caste affiliation of tolas in the field site.

Gram panchayat	Revenue village	Total no of tolas	No of selected tolas	Name of tola	Total households	Caste
Shyampur Kotaraha	ShyampurKotaraha	11	3	Karisa ka tola	50	Dalit and OBC
				Baiju Bhagat ka tola	80	General
				Devraj Yadav ka tola	55	OBC
Dakshin Telua	Telua	19	3	Bariarpur	66	General
				Navrahi	220	Dalit
				Khutai	30	Muslim
Total		30	6			

interviews also helped us to structure the questionnaire for the FGDs. The choice of key informants was based on developing a stakeholder list on flood information systems drawn from literature and conversations with local NGOs and elected representatives. We then expanded the list through snowball sampling. In each habitation, two focus group discussions were conducted, one exclusively with women and the other, with men – which led to twelve Focus Group Discussions (FGDs). Prior consent for focus group discussions and key informant interviews was requested from the respondents and in every instance choice of keeping individual identity anonymous was discussed in detail.

As is visible in Table 2 below, and as we will discuss later in detail, the key informant interviews led us to an androcentric universe, as men occupied institutional position related to generation, circulation and consumption of early warning information.

This actually provided valuable insights into how such androcentrism produces a ‘gender blind’ ‘official’ flood early warning system. Through our gender disaggregated focus groups, we were able to illuminate the pitfalls of such a system and this has been discussed in detail later in the paper.

The classification, collection, and representation of indigenous knowledge systems through brief encounters are a contested process (Agarwal, 1995; Smith, 2011). For the purpose of this study, we prefer to use the term ‘local knowledge’, to distinguish from indigenous and traditional knowledge, primarily because we recognize the study site, i.e., the Gandak river floodplain in India as a dynamic waterscape. As a trans-boundary river, the Gandak cuts across India and Nepal, and its floodplains have historically witnessed thriving social and migratory networks. Not only were there no known indigenous groups in the study area, but local communities also could not claim a long history of settlement in the specific study site, because of recurring displacement and resettlement of villages due to flood events. The river basin – one of the most populated regions in South Asia – is witness to high levels of migration, weakening the grip of caste-based occupation and inter-generational transfer of knowledge. We also broadened the understanding our fieldwork engagement by incorporating critical concerns around researching local knowledge (Blaikie et al., 1997; Goebel, 1998; Green, 2008; Sherry and Myers, 2002; Kelkar, 2007; Smith, 2011; Lebel, 2013). Such scholarship critiques the belief that local knowledge is held collectively, pointing at how gender, social groups, and individuals all have different perspectives on local knowledge. Secondly, it also points out that local knowledge is not held in isolation or a vacuum but is constantly interacting with wider knowledge networks. Thirdly, it recognizes that local knowledge is embedded in relations of power and hegemony. For this reason, researchers of local knowledge have to be wary of elites claiming their version to be representative.

As the methods section has illuminated, this research has engaged with such critiques of local knowledge, by accommodating the social reality of the research site, and diversifying sites of data collection to include different social and religious groups and then disaggregating the sample further by gender for focus groups.

4. When the river talks to its people: local knowledge and flood forecasting in the Gandak River Basin

Predictive knowledge of floods in the Gandak river basin is profoundly rooted in livelihood struggles, memories of dislocation, gendered practices and an understanding that emerges out of living with and surviving floods. The Gandak floodplains are a water-

Table 2
List of key informants interviewed.

Serial no	Age	Gender	Occupation	Gram panchayat
1	65	Male	Ex-Mukhiya, Dakshin Telua	Dakshin Telua
2	80	Male	Ex-Mukhiya, Bhagwanpur	Shivrajpur
3	45	Male	Ex-Mukhiya, Shivrajpur	Shivrajpur
4	65	Male	Ex-Chowkidar, Bihar Water Resources Department	Bairia
5	65	Male	Ex-Amin, Shyampur Kotraha	Shyampur Kotraha
6	65	Male	Ex-Chowkidar, Bihar Police, Nautan Thana	Shivrajpur
7	60	Male	Mukhiya, Shyampur Kotraha	Shyampur Kotraha
8	38	Male	Thana Officer in Charge, Nautan	Nautan
9	38	Male	BDO, Nautan Block	Nautan
10	64	Male	Amin, Dakshin Telua	Dakshin Telua
11	50	Male	Panchayat Member, Shivrajpur	Shivrajpur

Table 3
Categories of local knowledge at the study site.

Category	Explanation
Phenomenological	Relating to human sensation and sensory qualities. This involves seeing, hearing, feeling etc. However, it doesn't restrict to physical sensations alone but also investigates a wider range of emotions, such as memory, belonging, events, imaginations, social activity etc.
Ecological	Relating to non-human behaviour, phenomenon, and patterns.
Riverine	Relating to observations and measurements related to the river and its interaction with smaller streams and the floodplains. Any ecological aspect of flood forecasting that is related to the river is accommodated here.
Meteorological	Related to wind movements, cloud, and rain patterns.
Celestial	Related to the appearance of specific constellations in the sky.
Official	Related to information provided by the Government through radio, television, newspapers and circulated through word of mouth or mobile phones
Triangulated indicators	This category attempts to capture the dynamism of local knowledge. We use the word 'triangulation' to explain the process of knowledge validation that is arrived at through the cross verification of information derived from different sources. In the research site, it relates to knowledge produced through the interaction of the other categories, such as analyzing "official" early warning messages against "riverine' or "ecological" observations. It accounts for forecasting a flood event by bringing together different forms of local information, and not one indicator alone.

produced landscape or 'waterscape' (Swyngedouw, 1999) and a "phenomenon whereby water and power shape each other to generate a continuously evolving socio-nature" (Acharya, 2015:374). In waterscapes, knowledge co-evolves with political and ecological change. However, as our research shows, it does not take away its claim to robustness and should be documented as a sophisticated system that unceasingly accommodates change.

It attempts to attend to a critical gap in early warning system and hazards research and toolkits, where the concern around 'local' seems to be on how to provide communities with an early warning rather than appreciate and accommodate local forecasting knowledge. We interrogate such top-down approach to local populations, which depicts them as consumers of advanced information from "scientific" official systems rather than producers of their own forecasting knowledge. This paper attempts to classify local knowledge by borrowing from earlier works (Dekens, 2007b; Acharya, 2011; Irfanullah and Motaleb, 2011; Santha et al., 2014) but contextualizing it to the study site (Table 3). In the Gandak River basin, recording diverse flood forecasting indicators leads us to frame the following categories:

4.1. Phenomenological indicators

'Halla' (i.e., noise in Bhojpuri) appears as the principal early warning alert in the study sites. As floodwaters rise and approach the nearest house, the residents start shouting *"sariali ho, baad abatani"* (gather your things, the flood is approaching). The nearest house then picks it up and shouts it out for others in the vicinity. It is important here to note that *'halla'* is just not a warning alert from an individual house, but also a significant amount of cumulative noise coming from a habitation, as flood damage starts to take its toll. Hence shouting out alerts is just one part of *'halla'*. The other is the noise coming from the collapsing of '*geheri/bedi'* (bamboo and mud storage structures). The '*bedi* is a critical lifeline for the household as it stores an entire seasons supply of food grain. With the water eroding its base, the collapsing *'bedi'* generates its own noise and it is accompanied by agitated cries from the household as they desperately try to salvage the situation. The noise generated is significant and reaches a long distance. The collapsing *'bedi'* is also considered to be an indicator for the next households on the speed and depth of approaching floodwater. Hence *'halla*' conveys not only warning but also essential information based on which households take precaution.

For example, it has messages like: a *'bedi'* has collapsed in A's house, or water has reached the roof of B's house, or C has just lost a buffalo. News of such incidents provides important information to the next households on the movement of floodwaters. Awareness of the elevation of neighbours homestead land, or the height of the roof or the height of the cattle shed et al. allow householders to calculate when floodwaters will reach one's own house, and if it does, to what elevation. This then helps households to prioritise securing of food supplies and other essentials. In the case of flash floods, *'halla'* appears to be the most reliable system of early warning.

Apart from noise, specific sounds also act as an indicator of floods. Women mentioned that during flood season (mostly August) if they went to their agricultural fields and found *'chhap chhap paani'* (paani being water) close to the river bank in the morning they would assume an imminent flood event. '*Chhap- chhap'* is an onomatopoeic term that defines the sound the feet make while stepping on ankle length water. Hence the sound produced in ankle deep water in the agricultural field served to forecast floods.

4.2. Ecological indicators

Across the study site, many ecological indicators were reported. Some habitations informed that swift movement of ants meant either thick rain or floods. In another, the sight of small red ants moving with their eggs in their mouth indicated looming flood. As Chandrika Mahato, the ex-chowkidar[5] of the embankment mentioned:

[5] Guard.

> "There is a special type of black ant that is visible just before (and during) the onset of heavy rains. It starts coming out of the ground in large numbers with their eggs in their mouth and only travels in a straight line, like a railway track. However, if they do not travel in a straight line, then it is indicative of some other disturbance. If they do, then it indicates either heavy rains or a flood." (Mahato, pers comm. 2016)

Another type of ant also finds mention in different discussions. Red in colour, with light transparent wings, it is seen to fly in large numbers just before the rains. Appearance and behaviour of insects were believed to be a reliable indicator for rainfall across the study site. The notion of *'barsati keeda'* (i.e., insects of rain) was prevalent across the study site. The sudden emergence of a specific insect, or their proliferation in their numbers, or increasing intensity of their activity was both seen as indicative of rainfall.

The other ecological indicator for rainfall were different types of frogs. It is believed that the croaking of a '*peela mendak'* (yellow bellied frog) is a common indicator of rain. This frog was referred to as *'byagar byang'* by older women in another discussion. Locally, in women's group discussions, it was said that: "*agar byagar bang boli, to khub barish ho jayee*" (if the *'byagar'* frog croaks, heavy rainfall is assured). This frog is supposed to be unique, as it mostly stays near standing water after the first brief spell of rain at the onset of monsoon, and when it senses a heavy rainfall, croaks very loudly. Another type of frog mentioned was *'bengchi',* a smaller variety of frogs, which suddenly arrive before the rains. In one habitation, women said that they were very small and hard to find, but before heavy rains or floods they make a tremendous amount of noise. Interestingly, a majority of the responses on ecological indicators emerged from focus group discussions with women rather than men. Given this was based on fieldwork at a limited scale, we argue for more long-term interrogation of such patterns for further theoretical engagement.

4.3. Riverine indicators

The river emerges as the most reliable indicator for flood forecasting – mirroring the close relationship that people share with the Gandak River. As our findings reveal, knowledge of flood forecasting evolves out of the complex interaction of water and land. The river is under constant inspection during the monsoon for signs that indicate how floodwaters will affect the landscape. In this process, households with agricultural fields, or homestead land closest to the river have an important role to play. People have developed various methods of measuring the increasing water levels in the Gandak. The most common of them being the *'aar'/ 'kinara,'* i.e., the edge of the river bank itself. If the river water touches the edge of the riverbank, it is safe. But a flood is predicted the moment the river water tips over the edge of the bank.

A rigorous process of measurement of water level in the river is maintained during the monsoon. A *'khuta'* (long piece of wood) or a *'laga'* (long bamboo pole), is pushed into the riverbed, near the bank. The person who has his farm near the bank is vested with the responsibility to note the *'nishan'* (mark) to the point where the water touches the pole, and update it as and when the water level rises or falls. He then communicates the increasing height of the river water to everyone whenever he goes to the '*bazaar'* (market). The checking of the '*nishan'* on the '*khuta/laga'* is done daily, and by different people on different stretches of the river, so the observation is both frequent and granular. This measurement is also triangulated against radio news on water release from the Gandak barrage. It is important to note here that there is an intense engagement with the river to predict floods. This involves setting up a system of data collection (planting a '*khuta'* and assigning responsibility), keeping and updating data records (regular marking of water level), diversifying data sources (different data collectors in different river stretches) and a platform for communicating and sharing information *(bazaar)*.

Sometimes, specific terms are used to communicate the condition of a river, such as *'hari hari'* and *'chamak'*. The former refers to a sudden increase in the volume of river water, while *'chamak'* translates into 'shine' but it also indicates a healthy river in full flow. The changing colour of river water is also an important indicator. According to men in the study site, the river starts to get a *'gerua'* (i.e. ochre) or *'peela'* (i.e. yellow) colour at the onset of floods, which shows that a lot of water is coming from Nepal. This is seen as evidence to heavy rainfall occurring in the hills in Nepal, where soil washes off and enters the river. Hence the river acquiring a '*gerua*' (i.e. ochre) colour because of soil and silt, and subsequently losing its transparency, becomes an indicator for the arrival of flood waters. The smaller river channels also have a very important role to play. If they carry rainwater (i.e., 'shayar ka paani'), then the water in the streams moving towards the river appears clear (i.e., *'saaf'*). But when these smaller inland streams carrying rainwater towards the river start to lose their opacity, people recognize the entry of flood waters from the river into the village. This is indicative of breach in an embankment upstream, carrying flood water into the inland channels. Hence, the clouding of the water in smaller streams means floods are imminent as soil (i.e., *'mitti'*) from the main river (sometimes referred to as '*dariya'*) has entered streams in the habitation area.

The behaviour of the *'baikhi'* fish highlights the importance of the intersection of smaller streams and the main river. As the water in the river rises, it carries the '*baikhi'* fish with it, which is then transferred to the inland streams. It is believed that the fish begins to sense that they are close to 'naya paani' (i.e. clear/fresh water) coming from the inland channels. At this point, they start to jump in the river to enter the smaller streams. This jumping of *'baikhi'* fish is seen as an important indicator of the onset of floods. If the *'baikhi'* is not seen to jump, it is assumed that the water from the river will not overflow into the land. But if it is seen to jump, it indicates that the water level in the river is rising. However, if the fish is not at all visible, it indicates that the receding of water level in the river and rules out the possibility of a flood event.

While the presence of '*baikhi'* indicates rising water levels, its jumping indicates imminent floods, and its absence indicates a river water receding, hence nullifying the possibility of a flood. That one species of fish indicate three different types of behaviour of a river, highlights the fine-grained observations emerging out of intimate engagement with the waterscape. Interestingly, such observations emerged out of discussions with men from Dalit and other backward caste communities in the study site, who were historically related to river-based livelihoods, i.e., fishing, boating, before they moved into land-based occupations.

4.4. Meteorological indicators

Knowledge of the movement and pattern of clouds, rainfall and wind, also played a significant role in either flood forecasting, or heavy rain that could cause floods, or amplify damages caused by the same. Floods have a strong correlation with rainfall. Heavy rains used to result in floods, as the entire area used to get waterlogged, and the smaller inland streams used to get filled up, which meant they could not absorb water from the river, and slow down the speed and increasing volume of water entering from the river. Resultantly it used to spread over a larger area. Such nuanced understanding of local hydrology, as explained to us during our key informant interviews, also points to the fact that reading rainfall was integral to forecasting, as continuous rain for 24 h over a few days always led to floods. There was widespread consensus across our discussions and interviews, with both men and women across caste groups, that rainfall had decreased significantly in the study area since the 1990s and more so in the last ten years. Rainfall used to happen continuously for a week and maximum for 15–17 days, but it hardly lasted a week.

If the intensity and duration of rainfall have decreased in recent years, do local communities continue to depend on meteorological indicators for flood prediction? We placed this question in our focus groups and key informant interviews. We were informed discharge from dams upstream was now the major cause of floods. But rainfall indicators were seen to have continued importance for flood forecasting. Intensification of road and highway construction has amplified waterlogging on the other side of the embankment. On heavy rainfall days, this often leads to excess pressure building up on the embankment. If in this condition, water breaches a point in an embankment anywhere in the area, it gains momentum and force as it passes through areas already waterlogged. This then can lead to a more significant and damaging embankment breach.

People in the study site believe that rainfall patterns can be gauged easily by looking at the colour ('rang') and shape/form ('ruab') of the clouds. Both men and women agree that dark clouds cracks/dissipate easily, unable to bring heavy rains. However, only in our discussion with men, the direction from where the clouds appear seemed to have relevance in local communities of rainfall patterns. Clouds appearing in the northwest corner of the sky (i.e; 'bhandarkon') is believed to bring assured rain. It was also mentioned that clouds appearing from the southern corner of the sky never brings rain. But if they do, it can lead to a deluge.

4.5. Celestial indicators

Jab purwa purbaiyya pabe

tab sukhli gadaiya nao chalabe

[When the *west wind* (purbaiyya) starts blowing under the Purwa constellation, there will be so much rain one can sail a *boat* (nao) in the *low lying dry river channels* (sukhli gadaiya)]

Local communities relate rains to rain-related constellations, some of which is derived from traditional agricultural calendars. The Purwa constellation was viewed as a major rain-bearing constellation. The constellation mentioned was the Hathiya (elephant's trunk) constellation, which is visible in October. It is believed that under the Hathiya constellation, a spell of rain improves soil quality significantly. In the study site, celestial indicators were only discussed by Bariarpur tola - mostly populated by landed upper caste farmers. This was not mentioned in any other group discussion, including the one done in the same *tola* exclusively with women.

4.6. Official indicators

For the local community, the nature of the floods has changed from being dependent on heavy rainfall to large volumes of water released from the Gandak Barrage upstream at Valmiki Nagar. The dependence on formal sources of information, such as radio and newspapers, which track water releases from the barrage, has increased in the last few decades. There are announcements aired on the radio during the monsoon season, providing information on how much water has been released from the barrage. This is expressed in terms of cusecs or cubic feet per second. One cusec equals 28.317 l per second. It is understood that information on how much water has been released is communicated through the radio. But how that information travels to the radio station, newspapers and Government officials is quite unclear. At the District level, the District Magistrate receives the alert and then passes it on the Block Development Officer (BDO) and District Superintendent of Police (DSP). The BDO then shares the information with the local *mukhia* (i.e. village chief) and others using their cell phones. In parallel, the DSP's office furthers the information to the Station In Charge at the Block Police Station. He then alerts village chowkidars (i.e. guards) on their mobile phones. The Bihar Jal Sansadhan Bibhag (i.e. Bihar Water Resources Department) is another source of information. They get their information directly from the barrage where the water has been released, which is forwarded to the Junior Engineer (JE), who informs the local embankment chowkidars to alert people. If the risk is significant, the local police station communicates alerts directly. Using a hired vehicle, the police constable moves through villages, using a loudspeaker to announce the arrival of floods and for people to evacuate or take preventive measures. Hence, during a flood, three different people in a village, i.e. village chief, police guard and embankment guard, receive official information and is responsible for its circulation. It is important to note that in this system, information flows exclusively through men. The structural exclusion of women from public institutions means they are by default excluded from playing a role in generating flood forecasting knowledge or foster a gendered understanding of its development and circulation.

In the study site, there was significant trust on the flood early warning aired on the radio, rather than any other source, as mentioned before. However, the local radio samachar (i.e. news), is aired in only two slots, early morning, and late evening, mostly at 8 A.M. and 7:30 P.M. In between, it is rare for alerts to be aired unless it is a serious emergency. In case a large volume of water is released during the day, and there is imminent danger of an impending flood, the local administration is supposed to provide that information. The radio news alert only gives an estimate of the total volume of water released. This does not inform people of their exposure to risk. This has led to people working out a way to assess their risk, and that will be discussed in detail in the next section on triangulating indicators. However, there was a consensus in all our focus groups that people rarely saw a Government official announcing flood warnings. An elected *mukhiya* countered that, as he felt that people always complain about the absence of state services, while the fact is that in case of emergencies, officials or representatives do come to villages to make announcements. A former *mukhiya* shared his perspective balancing these opposite set of views. If officials did indeed arrive at the villages; they would take the vehicle through motorable roads. This meant flood alerts rarely reached most habitations located far away from the main road, or accessible through narrow earthen roads. This was mentioned in all the focus group discussions in habitations located closest to the river bank. This fertile area, a large patch of land which receives floodwater and has sandy solid, is known as the '*diyara'*. Unfortunately, such areas are disconnected from road access and electricity supply. Local communities in the '*diyara'* told us that officials rarely came to this area, especially during the rainy season where the earthen roads are difficult to negotiate. Hence, given the social intricacy of caste-based neighbourhoods, and spatial spread of the habitations, formal early warning systems do not seem to be working very well. Moreover, there is very little coordination between different arms of the state bureaucracy. This means that though information reaches the village, it comes from numerous sources, each source not talking to each other. The bazaar or the marketplace is still a significant news exchange platform. Early warning is heard either on the radio, seen on television or read in a broadsheet and discussed. As people come back to their habitations they share the news. The restriction of the everyday movement of women to house, farm and neighbourhood mean that they are disconnected from an important flood early warning information platform, the impacts of which we will discuss in detail later.

4.7. Triangulated indicators for early warning

Local knowledge of flood forecasting depends on triangulating a diverse set of indicators and sources of information. Official indicators were triangulated against ecological, phenomenological, riverine, celestial, and meteorological indicators for increasing reliability and making decisions. This process owes its origin to the prolonged experience of living in a shifting landscape, coupled with exposure to new knowledge accessed through television, mobile phones and newspapers. Local communities discussed with us how they use a 25 per cent formula. The only information accessed through the radio is the quantity of water released. It does not inform them which areas will be flooded and the time of the same. People have an unclear number to make their choices on, which the total water released in cusecs. Over time, they have seen that the day release of water from the barrage upstream is announced on the radio, it takes, on an average, 3–4 days for that water to reach their village. However, this is based on the volume of released water. More the release volume, the faster the water reaches the village. In most cases, local communities believe that only 25% of the released water reaches the villages in the study area, so if 1 million cusecs are being released, only 250,000 cusecs will reach the village. Similarly, if only 100,000 cusecs are released, it will take more time to reach, and will have a much lesser/negligible impact. Once the water level in the starts to rise, people who live close to the river start to measure it using a 'laga' or a bamboo pole. They intermittently share the information of the height of the river in terms of the measuring tool, i.e., ek (one) laga, do (two) laga, teen (three) laga, etc. The flow of the current of the river is also observed carefully. If the current is flowing towards Gopalganj, downstream to the west, the communities in the study site believed that flood will move towards villages in that area. However, if it also rains heavily and water is also released from the barrage, then the chance of flood occurrence goes up. Even if the volume of release is deemed safe going by the 25% rule, the fact that the smaller streams are already full of rainwater means that it could lead to a flood. Based on these factors communities work out the possible height of the floodwater in terms of 'feet'. This message then circulated through *'halla'*. The higher the measurement is in terms of feet (ft), the greater the risk. A lot of preparations prior to the floods are made on the basis of these calculations, like the amount of food to be stocked on the roof, whether livestock needs to be shifted or not.

Communities have managed to deal with floods using these complex calculations involving several indicators. What they have suffered from - and what evades such complex and nuanced calculation - are flash floods that occur from a breach in the embankment. The 1993 flood, which caused a lot of death and destruction, was because of the breach of the embankment at Laukariya. However, people do say that they had correctly spotted the point where the river was cutting into the embankment and put sacks filled with soil and sand along that spot to keep the embankment intact, but the river finally won. It devastated the habitations in higher areas, but left the lower areas safe, much to the surprise of the local population. Hence, local knowledge system of flood forecasting is not guaranteed success, but it is the best that people have.

5. Towards acknowledging local knowledge in flood forecasting

Understanding the production of local knowledge of flood forecasting for transboundary rivers in South Asia needs long-term research. This exploratory research reveals that people living in the Gandak river basin have developed a highly evolved local knowledge system to forecast floods. Our research also reveals the gendered construction of such knowledge systems.

The entire official early warning system operational in the study site is androcentric as 'official' information circulates between men. Women do not get news of flood waters ('paani ka khabar') directly from officials but must wait for the men in their household to bring the news to them. This is because of the way the message, mostly composed of obscure numbers, and aired on the radio, needs mediation and interpretation, which is a role played by men in the household. Social and cultural barriers do not allow women to access news from the *'bazaar'*, as they are not encouraged to engage with such spaces. Hence women are dependent on men to give them information obtained from official sources about a flood event. This raises a question on how households in which most men have migrated, or single women headed ones, will access information that is vital to their survival. This is especially critical for women in Dalit households, as, in the study site, cases of men leaving the village in search of work in urban centres outside Bihar were mostly from smallholder/landless Dalit homes. The socioeconomic vulnerability of these families is bound to amplify during floods, where, in most cases, women are left to fend for themselves.

Our gender disaggregated focus group discussions highlighted how women have a fine-tuned understanding of various indicators for flood forecasting, which in some cases overlap while in some cases are quite distinct from the indicators perceived by men. In fact, some of the key ecological and phenomenological indicators - those of specific frogs and insects, and sound from ankle height water in the fields – came from women's group discussions, and not from men's. It, therefore, leads us to question if gendered access to space has shaped different understanding of indicators and produced differentiated knowledge. We can only throw open this question for future research. Our research also shows that local knowledge of early warning systems mirrors the gender concerns of official early warning systems. Women do not play any role in several knowledge generation activities, such as measuring the rise in the level of the water in the river using the '*laga'* as they are viewed as areas of men's expertise. The same was noticed with the understanding of celestial indicators for rainfall which even women from the same upper caste habitation were not aware of. Social and structural barriers seem to prevent women from engaging with a wider process of knowledge production. It was also clear that women's knowledge and understanding do not find legitimacy with men. Actionable knowledge is developed and produced by men, where different forms of early warning indicators and information are processed and legitimized and decisions on next steps are taken.

Interestingly, and as noted in previous research on flood warning systems, the entry of cellular services into the landscape (Parker and Handmer, 1998) and improved education for young girls is reshaping the flow of communication and hence the production and consumption of flood forecasting knowledge. For the family of migrant workers, where women are left behind in the village for extended periods of time, cellular services have enabled them to call doctors to their doorsteps during floods, coordinate with their family members, and keep their husbands informed and relatives updated about their well-being. Similarly, the Bihar governments 'Bicycle to Girls' Scheme has provided young girls across caste groups bicycles to attend school, which has allowed them greater mobility and wider access to spaces which was inconceivable earlier (Muralidharan and Prakash, 2013). These developments are redefining women's access to space and information in the study area.

Mobile phones are also reshaping official early warning systems by improving communication between different departments. For instance, BDOs now directly inform *'mukhias'* of floods, and they get regular updates of the extent of floods and plan relief in return. Sluice gate operations on the embankment are now faster because a quick call to the *'chowkidar'* from the engineer ensures faster operation. All this, interestingly, is not state-endorsed. Government staff is investing in mobile phones themselves. Engineers are buying mobile phones for embankment *'chowkidar'*s from their own pockets. Officially, there is no budget for such technology, even though it is far-reaching and critical for adoption. Strengthening and improving the existing system of local knowledge on flood forecasting, coupled with practical ways to include latest technologies such as mobile phones, could make things easier for people in the Gandak floodplains, especially women.

What has increased uncertainty in the study site is not just concerns of changing monsoons, but how infrastructure development – roads, highways, railway tracks - is changing local hydrological regimes. In such a rapidly changing context, the survival of local knowledge systems of forecasting may seem uncertain, but our research shows that communities in the study site are successfully accommodating such changes into their knowledge systems. The triangulation ones see in action in the study areas if evidence of such evolution. However, such knowledge is largely ignored by state agencies. Given that rainfall patterns in the area is shifting, and the fickle nature of Gandak as a course shifting river system, there is a need for engaging with local knowledge systems to not only enrich data on climate and hydro-meteorological science but also improve the content and delivery of centralized early warning systems. But in order for that to happen, a conversation needs to start between formal forecasting and early warning systems, and local ones.

"Local", as we argue in this context, should be recognised as a site of knowledge generation on flood forecasting, rather than just a site for dissemination of early warning. Local knowledge of flood forecasting in the study site, especially a habitation based approach, would help to accommodate the hyper-local reality of floods in the Gandak river basin, which is not necessarily the case with a top-down techno-bureaucratic system. Also, while efforts at community-based early warning systems (UN-ESCAP, 2016) seeks to project a more granular and participatory approach, the idea there is to find proper pathways to communicate a message effectively rather than engage with and strengthen local knowledge systems.

We agree with Parker and Handmer (1998:57), that local knowledge systems, like their 'official' counterpart, could be prone to "errors, miscalculations and late detection." However, we also argue that in the Gandak floodplain, a dichotomous understanding of local and official is problematic, especially since local knowledge systems depend on official flood early warning alerts as a critical input. In terms of bringing local knowledge and official early warning closer, we propose knowledge exchange sessions at the block level between officials and their ground staff and local communities. But we also argue that more work is needed to both improve the quality and content of official early warning alerts, which should be a priority for Government agencies. Improved official flood early warning will help increase the reliability of triangulated forecasts. The current androcentric official early system is unaware of gendered vulnerabilities of flood-affected families. We would also like to issue a caveat regarding romanticising local knowledge systems, as such processes also exclude women's lived experience. Any engagement with the local knowledge of flood forecasting needs to understand how it is embedded in a cross-cutting matrix of gender, caste and power. However, it is also important to acknowledge this sophisticated system, and local level flood management plans should be amended to include local knowledge exchange engagements. This could be the first step towards official recognition of local knowledge systems.

Acknowledgements

This work was carried out by the Himalayan Adaptation, Water and Resilience (HI-AWARE) consortium under the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA) with financial support from International Development Research Centre (IDRC), Ottawa, Canada. IDRC Project Number 107641. This work was also partially supported by core funds of ICIMOD contributed by the governments of Afghanistan, Australia, Austria, Bangladesh, Bhutan, China, India, Myanmar, Nepal, Norway, Pakistan, Switzerland, and the United Kingdom.

Disclaimer

The views expressed in this work are those of the creators and do not necessarily represent those of the UK Government's Department for International Development, the International Development Research Centre, Canada or its Board of Governors. In addition, they are not necessarily attributable to ICIMOD and do not imply the expression of any opinion by ICIMOD concerning the legal status of any country, territory, city or area of its authority, or concerning the delimitation of its frontiers or boundaries, or the endorsement of any product.

References

Acharya, A., 2015. The cultural politics of waterscapes. In: Bryant, R.L. (Ed.), The International Handbook of Political Ecology. Edward Elgar, Cheltenham, pp. 373–386. https://doi.org/10.4337/9780857936172.00036.

Acharya, S., 2011. Presage biology: lessons from nature for weather forecasting. Indian J. Tradit. Knowl. 10 (1), 114–124. ⟨http://nopr.niscair.res.in/handle/123456789/11072⟩.

Agarwal, A., 1995. Dismantling the divide between indigenous and scientific knowledge. Dev. Change 26, 413–439. https://doi.org/10.1111/j.1467-7660.1995.tb00560.x.

Alam, S.M.N., 1990. Perceptions of flood among Bangladeshi villagers. Disasters 14 (4), 354–357. https://doi.org/10.1111/j.1467-7717.1990.tb01080.x.

Blaikie, P., Brown, K., Stocking, M., Tang, L., Dixon, P., Sillitoe, P., 1997. Knowledge in action: local knowledge as a development resource and barriers to its incorporation in natural resource research and development'. Agric. Syst. 55 (2), 217–237. https://doi.org/10.1016/S0308-521X(97)00008-5.

Dandekhya, S., England, M., Ghate, R., Goodrich, C. G., Nepal, S., Prakash, A., Shrestha, A., Singh, S., Shrestha, M.S., Udas, P. B., 2017. The Gandaki Basin – maintaining livelihoods in the face of landslides, floods, and drought. HI-AWARE Working Paper 9. HI-AWARE, Kathmandu.

Census of India., 2011. Planning Commission, Government of India.

Dekens, J., 2007a. Local Knowledge for Disaster Preparedness: A Literature Review. International Centre for Integrated Mountain Development, Kathmandu.

Dekens, J., 2007b. The Snake and the River Don't Run Straight: Local Knowledge on Disaster Preparedness in the Eastern Terai of Nepal. International Centre for Integrated Mountain Development, Kathmandu.

DHA, 1994. Yokohama strategy and plan of action for a safer world. In: Proceedings of the World Conference on Natural Disaster Reduction. Yokohama.

Dixit, A., 2003. Floods and vulnerability: need to rethink flood management. In: Mirza, M.M.Q., Dixit, A., Nishat, A. (Eds.), Flood Problem and Management in South Asia. Springer, Dordrecht, pp. 155–179. https://doi.org/10.1023/A:1021134218121.

Dutta, D., Herath, S., 2004. Trend of floods in Asia and flood risk management with integrated river basin approach. In: Proceedings of the 2nd International Conference of Asia-Pacific Hydrology and Water Resources Association, Singapore, vol. 1, pp. 55–63.

Ferand, C., 2017. At least 41 million people affected in floods in India, Bangladesh and Nepal, UN says. The Independent. Accessed at ⟨https://www.independent.co.uk/news/world/asia/india-floods-bangladesh-nepal-millions-affected-says-un-a7920721.html⟩, (Date of Access – May 23, 2018).

Ghosh, D., 2016. Ecosystem Management: Towards Merging Theory and Practice. NIMBY Books, New Delhi.

Gladfelter, S., 2018. The politics of participation in community-based early warning systems: building resilience or precarity through local roles in disseminating disaster information? Int. J. Disaster Risk Reduct. 30, 120–131. https://doi.org/10.1016/j.ijdrr.2018.02.022.

Goebel, A., 1998. Process, perception and power: notes from 'participatory' research in a Zimbabwean resettlement area. Dev. Change 29 (2), 277–305. https://doi.org/10.1111/1467-7660.00079.

Government of Bihar, 2013. Hazard, Vulnerability and Capacity Assessment Report.

Green, L.J.F., 2008. 'Indigenous knowledge' and 'science': reframing the debate on knowledge diversity'. Archaeol.: J. World Archaeol. Congr. 4 (1), 144–163. https://doi.org/10.1007/s11759-008-9057-9.

Hirabayashi, Y., Mahendran, R., Koirala, S., Konoshima, L., Yamazaki, D., Watanabe, S., Kanae, S., 2013. Global flood risk under climate change. Nat. Clim. Change 3 (9), 816. https://doi.org/10.1038/nclimate1911.

Irfanullah, M.H., Motaleb, A.H., 2011. Reading nature's mind: disaster management by indigenous peoples of Bangladesh. Indian J. Tradit. Knowl. 10 (1), 80–90.

Kelkar, M., 2007. Local knowledge and natural resource management: a gender perspective. Indian J. Gend. Stud. 14, 295–306. https://doi.org/10.1177/097152150701400205.

Kelman, I., Mercer, J., Gaillard, J.C., 2012. Indigenous knowledge and disaster risk reduction. Geography 97, 12. ⟨https://www.geography.org.uk/Journal-Issue/161dfa89-a14f-4bc9-b065-d47829fc8126⟩.

Lebel, L., 2013. Local knowledge and adaptation to climate change in natural resource-based societies of the Asia-Pacific. Mitig. Adapt. Strateg. Glob. Change 18, 1057–1076. https://doi.org/10.1007/s11027-012-9407-1.

Lutz, A.F., ter Maat, H.W., Wijngaard, R.R., Biemans, H., Syed, A., Shrestha, A.B., Wester, P., Immerzeel, W.W., 2018. South Asian river basins in a 1.5 °C warmer world. Reg. Environ. Change. https://doi.org/10.1007/s10113-018-1433-4.

Mirza, M.M.Q., 2011. Climate change, flooding in South Asia and implications. Reg. Environ. Change 11 (1), 95–107. https://doi.org/10.1007/s10113-010-0184-7.

Mishra, D.K., 1997. The Bihar flood story. Econ. Polit. Wkly. 32 (35), 2206–2217. ⟨https://www.jstor.org/stable/4405794⟩.

Mishra, D.K., 2001. Living with floods: people's perspective. Econ. Polit. Wkly. 36 (29), 2756–2761. ⟨https://www.jstor.org/stable/4410885⟩.

Mohapatra, P.K., Singh, R.D., 2003. Flood Management in India. Nat. Hazards 28 (1), 131–143. https://doi.org/10.1023/A:1021178000374.

Muralidharan, K., Prakash, N., 2013. Cycling to school: increasing secondary school enrollment for girls in India. Am. Econ. J.: Appl. Econ. Am. Econ. Assoc. 9 (3), 321–350. ⟨http://www.nber.org/papers/w19305⟩.

Mustafa, D., Gioli, G., Qazi, S., Waraich, R., Rehman, A., Zahoor, R., 2015. Gendering flood early warning systems: the case of Pakistan. Environ. Hazards 14 (4), 312–328. https://doi.org/10.1080/17477891.2015.1075859.

National Disaster Management Authority, 2008. National Disaster Management Guidelines: Management of Floods. Government of India, New Delhi.

Parker, D.J., Handmer, J.W., 1998. The role of unofficial flood warning systems. J. Conting. Crisis Manag. 6, 45–60. https://doi.org/10.1111/1468-5973.00067.

Paul, B.K., 1984. Perception of and agricultural adjustment to floods in Jamuna floodplain, Bangladesh. Hum. Ecol. 12 (1), 3–9. https://doi.org/10.1007/BF01531281.

Paul, S.K., Routray, J.K., 2010. Flood proneness and coping strategies: the experiences of two villages in Bangladesh. Disasters 34 (2), 489–508. https://doi.org/10.1111/j.1467-7717.2009.01139.x.

Perumal, M., Bhabagrahi, S., 2007. Limitations of real-time models for forecasting river flooding from monsoon rainfall. Nat. Hazards 42, 415–422. https://doi.org/10.1007/s11069-006-9082-1.

Rouyer, A.R., 1994. Explaining economic backwardness and weak governing capability in Bihar state in India. South Asia J. South Asian Stud. 17 (2), 63–89. https://doi.org/10.1080/00856409408723206.

Santha, S.D., Gahana, P., Aswin, V.S., 2014. Local knowledge, early warning and coastal hazards: participatory inquiry among fishworkers in Kerala, India. Action Res. 12 (3), 273–292. https://doi.org/10.1177/1476750314532504.

Schware, R., 1982. Official and folk flood warning systems: an assessment. Environ. Manag. 6 (3), 209–216. https://doi.org/10.1007/BF01866884.

Schware, R., 1984. Flood information systems: needs and improvements in Eastern India. Environ. Manag. 8 (1), 55–66. https://doi.org/10.1007/BF01867873.

Sherry, E., Myers, H., 2002. Traditional environmental knowledge in practice. Soc. Nat. Resour. 15, 345–358. https://doi.org/10.1080/089419202753570828.

Singh, O., Kumar, M., 2013. Flood events fatalities and damages in India from 1978 to 2006. Nat. Hazards 69, 1815–1834. https://doi.org/10.1007/s11069-013-0781-0.

Singh, P., 2008. The colonial state, zamindars and the politics of flood control in north Bihar (1850–1945). Indian Econ. Social Hist. Rev. 45 (2), 239–259. https://doi.org/10.1177/001946460804500203.

Singh, P., Ghose, N., Chaudhary, N., Hansda, R., 2009. Life in the Shadow of Embankments – Turning Lost Lands into Assets in the Koshi Basin of Bihar, India. International Centre for Integrated Mountain Development, Kathmandu.

Smith, T.A., 2011. Local knowledge in development (geography). Geogr. Compass 5 (8), 595–609. https://doi.org/10.1111/j.1749-8198.2011.00443.x.

Swyngedouw, E., 1999. Modernity and hybridity: nature, regeneracionismo, and the production of the Spanish waterscape, 1890–1930. Ann. Assoc. Am. Geogr. 89 (3), 443–465. https://doi.org/10.1111/0004-5608.00157.

UNISDR, 2011. Revealing Risk Redefining Problem. Global Assessment Report on Disaster Risk Reduction. United Nations. Accessed at 〈https://www.preventionweb.net/english/hyogo/gar/2011/en/home/download.html〉, (Date of Access May 25, 2018).

United Nations – Economic and Social Commission for Asia and the Pacific (ESCAP), 2016. Flood Forecasting and Early Warning in Transboundary River Basins: A Toolkit. UNESCAP, Bangkok, Thailand.

United Nations Environment Programme (UNEP)-Global Environmental Alert Service (GEAS), 2012. Early warning systems: a state of the art analysis and future directions. Environ. Dev. 4, 136–171 (Article reproduced from UNEP-GEAS).

Wijngaard, R.R., Lutz, A.F., Nepal, S., Khanal, S., Pradhananga, S., Shrestha, A.B., Immerzeel, W.W., 2017. Future changes in hydro-climatic extremes in the Upper Indus, Ganges, and Brahmaputra River basins. PLoS One 12 (12), e0190224. https://doi.org/10.1371/journal.pone.0190224.

Xenariosa, S., Kakumanuc, K.R., Nagothub, U.S., Kotapatid, G.R., 2017. Gender differentiated impacts from weather extremes: insight from rural communities in South India. Environ. Dev. 24, 156–169. https://doi.org/10.1016/j.envdev.2017.05.002.