Water Policy 21 (2019) 999–1016

Addressing water-related shocks and coping decision through enhanced community participation: case studies from Ganga basin, Uttarakhand, India

Divya Sharma[a], Neha Khandekar[b] and Kamna Sachdeva[a,*]

[a] *Teri School of Advanced Studies, Plot No. 10, Institutional Area, Vasant Kunj, Institutional Area, New Delhi, India*
**Corresponding author. E-mail: kamna.sachdeva@terisas.ac.in*
[b] *Ashoka Trust for Research in Ecology and the Environment (ATREE), Royal Enclave, Srirampura, Jakkur, Bengaluru, Karnataka, India*

Abstract

Farming communities in the Upper Ganga basin, nestled in the Himalayan region, are finding it extremely difficult to face water-related shocks, which stand to profoundly impact their quality of life and livelihoods, due to climate change. Often, coping strategies (technological or institutional interventions), developed by planners, become counter-productive as they are not in cognizance with the end user community. This study presents a methodology to enable incorporation of community knowledge and expectations in planning by integrating participatory rural appraisal (PRA) with geographic information systems, leading to better informed coping strategies. As part of this, we create thematic maps which: (i) capture information on a spatial scale (otherwise lost during PRA), (ii) facilitate community participation for further research and planning in their contexts, and, (iii) co-create knowledge to develop a shared understanding of water-related hazards at the village level. The proposed methodology is presented through three case study sites – two in the plains (<500 masl) and one in the middle (500–1,500 masl) elevation regions of Upper Ganga basin. We show how this way of approaching context analysis facilitates community involvement as well as co-creating a knowledge base which can help researchers and government officials with mindful planning of interventions in the area.

Keywords: Floods; Groundwater; Participatory geographical information system (PGIS); Springs; Upper Ganga basin; Water-related shocks

Introduction

Estimates suggest that a population of 1.4 billion people is going to be affected by climate change and related water shocks in Asia (Immerzeel *et al.*, 2010). Among all other primary river basins (Indus,

doi: 10.2166/wp.2019.026

Brahmaputra, Yangtze, and Yellow rivers), only the Ganges basin has shown a negative trend in terms of snow and ice storage (Immerzeel *et al.*, 2010). The Ganga basin has been highlighted as the most vulnerable basin in terms of climate change (Maplecroft, 2011). Mountain communities within this basin rely entirely on springs for water consumption (Negi & Joshi, 2002) and these springs are drying up at a rapid rate (Valdiya & Bartarya, 1989; Sati, 2005; DST 2017) due to urbanization and ecological degradation. This is further exacerbated by changes in climatic trends like rising temperature, increasing rainfall intensity, and reduction in winter rains (Tambe *et al.*, 2012), affecting various stages of the hydrological cycle.

Downstream, the floodplains of the basin constitute one of the highest yielding aquifers (Mukherjee *et al.*, 2015) resulting in thriving agriculture in the region. According to Rodell *et al.* (2018), groundwater in northern India is being depleted at a rate of 19.2 giga tons per year. The depletion of groundwater can be attributed to abstraction for irrigation as well as for non-agricultural purposes. Over the past decades, groundwater has become a major source of irrigation in India (Kulkarni & Thakkar, 2012; Kumar *et al.*, 2013). Groundwater pumping has also increased in the region, which is evident by the increasing number of pumps (Scott & Sharma, 2009). The absence of a regulatory institution at the local level becomes problematic in terms of lack of any control over granting permissions to pump (Scott & Shah, 2004). Climate change and groundwater are closely linked, as changes in evapotranspiration, precipitation, and rainfall intensity will affect the aquifer recharge (MoWR, 2009). All these drivers are acting together to increase depletion rates in pockets in North India, brewing a recipe for an impending groundwater crisis situation. Traditionally, issues related to water availability have been studied at a macro scale using remote sensing analysis (Muthuwatta *et al.*, 2010). However, a spatial understanding of differential water access issues at the micro level is barely developed. Micro level study is important for introducing better groundwater governance and hence facilitate proactive preparation for crisis situations.

Another water-related hazard looming over the basin is flash floods. Short duration heavy rainfall events have exacerbated the flood hazards in the plains. Further, there has been a prediction of higher intensity floods due to an increase in monsoon flows (Whitehead *et al.*, 2015) in the Ganges basin. The June 2013 flood event in the Upper Ganga basin has been linked to anthropogenic footprint and climate change (Cho *et al.*, 2016). Deforestation in the upper catchments leads to loose topsoil cover, and in the event of flash floods, streams and rivers carry excess sediments downstream (Khan *et al.*, 2018). Riparian communities residing close to the streams have memories of the natural flow regime of the river and have organized their lives and livelihoods around it for generations. Changes in frequency and intensity of flooding due both to climatic and anthropogenic reasons (hydropower projects) (Krause, 2010) cause a perplexing situation for riparian communities, making it difficult for them to be prepared in advance. Flood flows benefit farmers living downstream as they bring good quality nutrient-rich soil from mountains, depositing it on the floodplains, thereby enhancing the productivity of the soil. However, the altered nature of flows – be it due to climate change or hydropower projects – is confusing farmers. Developing a time series understanding of disturbances in the lives of riparian communities due to alterations in flows is still lacking.

Collective action for managing a shock not only calls for social learning and a shared understanding of the current situation but also foresightedness about how the situation might evolve in the future (Pahl-Wostl, 2007). Thus, to engage with research and planning pertaining to the above-stated issues, the participation of the community becomes important. Local knowledge and understanding of the situation will help in planning, and in creating mutual trust, thus making any intervention more acceptable to all the stakeholders (Mosse, 1995).

To engage communities in a dialogue, approaches like participatory rural appraisal (PRA) have been commonly used as one of the methods of interaction in many development-related studies (Bebbington, 2000). PRA tools have been used to record attitudes, perceptions, and beliefs of communities and provide an access to their worldview of natural resource management (Chambers, 1994; Zanetell & Knuth, 2002).

However, the knowledge created with the help of the community is often not used to its full potential for planning purposes. Maps created through PRA have spatial information in a figurative sense and cannot be reproduced precisely to scale. Attributes recorded cannot be defined in terms of latitude, longitude, and elevation so that they can be used for further research and investigation.

One major method to consider spatial information more accurately is to use a geographical information system (GIS)

> '*Geographic information systems combine hardware, software, data, people, procedures, and institutional arrangements to collect, store, manipulate, analyze, and display information about spatially distributed phenomena for the purpose of inventory, decision making and/or problem-solving*. (Nyerges, 1993)'

GIS as a knowledge system and tool has immense potential to gather, process, and analyze information. This approach to GIS has been extensively used for understanding the environment and natural resources to aid decision-making processes (Maguire *et al*., 1991). Overlaying different thematic layers can bring out a complete picture of the situation in front of researchers and planners. But traditional GIS has a top-down approach and relies on data collection and interpretation of the results from the analyst's perspective (Weiner *et al*., 1995). Furthermore, it is costly and requires background knowledge, thus it cannot be taken to the rural community directly.

Research suggests that creation of an environment for social learning is crucial within the paradigm of adaptive water management (Pahl-Wostl, 2007). Moreover, the usefulness of information exchange within various stakeholders in social learning, to broaden the outlook on problem analysis and solving, has been stressed. Pahl-Wostl (2007) also highlights that information and communication technologies provide an enabling environment to initiate dialogues and build the capacity of the community. Participatory GIS (PGIS) is one such tool. PGIS as a method offers mapping geospatial information with the help of community stakeholders (Kumar *et al*., 1994; Elwood, 2009; Jankowski, 2009). Also, as a qualitative GIS tool, PGIS calls for an inductive, interpretive approach for co-creating knowledge and for highlighting data's contextual meaning (Tripathi & Bhattarya, 2004). PGIS is considered to be a community application of a multiple range of geographical information technology and systems (IIED, 2009). IIED (2009) also highlights that PGIS facilitates spatial specificity, social inclusivity, and capacity enhancement. Moreover, PGIS has been widely acknowledged as a participatory decision-making tool (Chingombe *et al*., 2015).

Drawing upon PGIS and its usefulness, our paper applies the technique in three study sites within the Upper Ganga basin thereby presenting a methodology which can go beyond PRA. This will help researchers and other stakeholders to create maps, where spatial information is not lost and can be built on progressively for desired outcomes, be it for developmental planning at sub-national level or invoking collective action at community level to cope with related hazards.

The following sections show how the study attempts to create a shared understanding of water-related shocks and water availability at village level, with PRA and PGIS tools. The idea has been to achieve:

(1) *social inclusion,* as a community's approach to dealing with a hazard is unique owing to their traditional knowledge; (2) *spatial specificity and knowledge integration* by involving various stakeholders in the exercise and incorporating their narratives on the map (PGIS) to create a visual story. The maps generated have been used to initiate dialogues with government officials in the concerned water management departments as well as the scientific community involved in larger research work by presenting the work in various forums; (3) Creation of *environment for social learning*, using PGIS maps as tools, to *initiate dialogues* and *build capacity* of all stakeholders.

Thus, the aim behind this research is to analyze the gaps between existing methodologies generally adopted to assess water-related risks and to propose a more integrated approach for the study region using PGIS. By applying the above-mentioned principles of PGIS, the results endorse that this technique helps in bridging the existing gap between academic sciences, technology, community, and planning.

Study area and cases

The study sites fall within the plains (<500 masl) and middle elevation (500–1,500 masl) regions (situational analysis ref.) of the Upper Ganga basin in the state of Uttarakhand, India. Within the state, the Upper Ganga basin boundaries extend from 400 masl to 1,500 masl (Bhadwal *et al*., 2017). Villages (as indicated in Figure 1(a)) are selected to focus on three major areas of water-related hazards emerging in the region, as discussed in the previous section: drying springs in middle elevation regions,

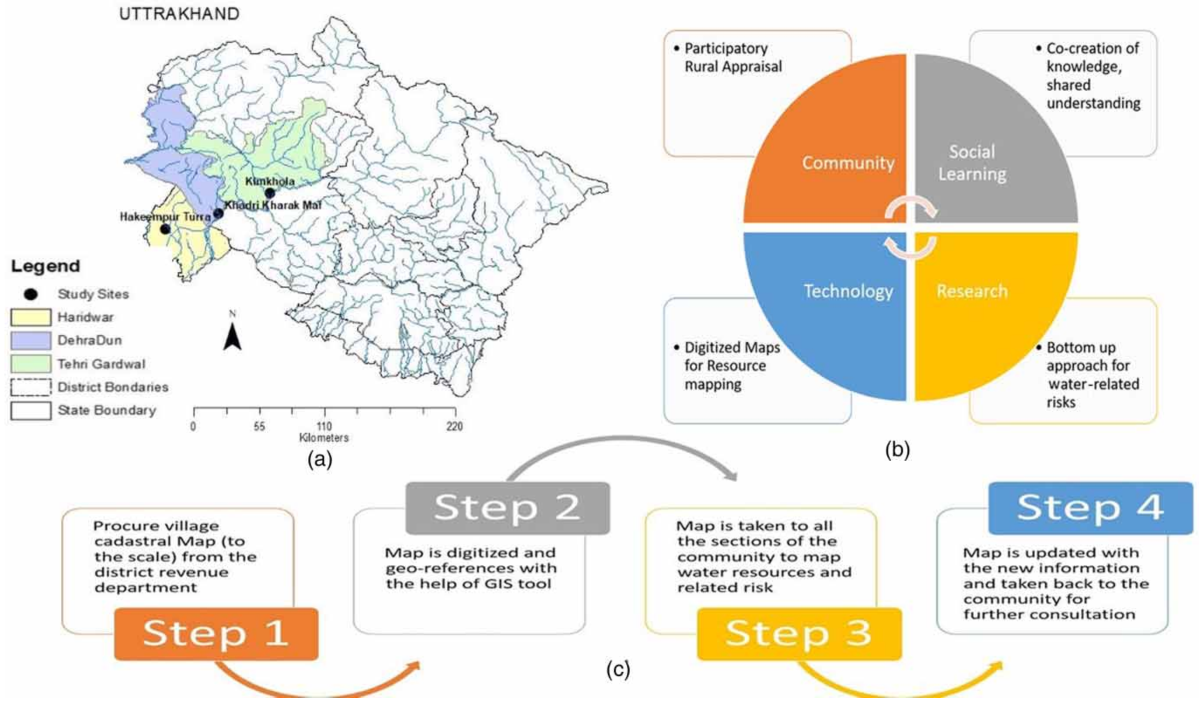


Fig. 1. (a) Case study sites, State of Uttarakhand, India; (b) study components and interactions; (c) four-step methodology for participatory GIS mapping.

floods and flash floods and depleting groundwater in the plains region. The details of the study sites are shared below and are also summarized in Table 1.

Hakimpur Turra village falls under the Bhagwanpur block in the Haridwar district of Uttarakhand, on the banks of the River Sonali, a tributary of the Ganges in the plains region. The village has a total geographic area of 283 hectares, of which 90 hectares is agricultural land. There are 419 households with a total population of 2,641 people. Residents rely completely on groundwater for domestic and irrigation purposes. The largest proportion of the population in the village (76.64%) belongs to Other Backward Caste (OBC) group. The remaining 23.36% belongs to the communities under the Scheduled Caste (SC) group (GOI, 2011). The settlements within the village are clustered as per communities' cultural background and ethnicity. The well-off farmers mainly belong to groups within OBC communities, owing to their having a major share of the land, whereas medium and small sized lands are owned by an economically poor SC group.

Khadri Kharak Maf is a town also located in the plains of the basin, at the confluence of the River Song and Ganges and downstream of Veerbhadra barrage on the River Ganges. Administratively, it falls

Table 1. Study site details.

	Hakimpur Turra (Haridwar)	Khadri Kharak Maf (Dehradun)	Kimkhola Tehri (Gharwal)
Total geographical area of settlement	282.88	NA	117.5
Altitude of the settlement (masl)	267	340	1341
Main ethnic group/caste	OBC, SC	Scheduled Tribe (ST), SC	Ghardwali Rajput, SC
Number of households	416	200	95
Distance to the nearest water sources (meters)	0–200	0	1–500
Population	2,641	8,000	413
Average household size	7–8	7–8	4–5
Livelihood sources	Agriculture, farm and off-farm labor, private and government jobs, self-business	Agriculture, farm and off-farm labor, private and government jobs, self-business	Agriculture, farm and off-farm labor, private and government jobs, self-business
Type of water resources	Groundwater	River	Spring and stand posts
Associated risk	Depletion of groundwater, increase in depth of extraction	Flash floods	Drying of springs, reduced water supply
Social dynamics related to risk	Marginal community is more affected due to high cost associated with deeper groundwater extraction	Only *Buksa* tribe has land near river	SC community has limited access to both stand posts and springs
Coping/adaptation (current)	Creating a double bore, increase in the motor power for more water	Embankments	Additional water tankers and stand posts
Community-based coping/adaptation (proposed by community during study)	Change in cropping pattern, groundwater governance	Relocation	Spring restoration, water harvesting

Source: Census 2011, field work.

under Dehradun district. It is divided into six wards. Ward numbers 1 and 6 are occupied by members of the *Buksa* tribe, falling under a scheduled tribe as per the Government of India (GOI). Remaining wards are largely inhabited by members of the *Garhwali* community. While *Buksas* (Awais & Khan, 2014) work primarily as farm and off-farm laborers and own small businesses within the town, *Garhwalis* are large landowners and also own businesses, shops, and are employed in government and private sectors. The settlement of the *Buksa* tribal community is close to the Ganges. Therefore, they are the most affected in any event of flooding in the river.

The third case study site, **Kimkhola** village, is in the middle elevation region and falls under Devprayag block in Tehri Garhwal district. The valley region hosts the confluence of the Bhagirathi and Alaknanda rivers which join together to form the Ganga. The village has people belonging to two different communities: the *Garhwalis* and *Lohar* communities belong to SC groups. The *Garhwali* community owns larger areas of agricultural land and is primarily engaged in farming. People from the *Lohar* community mostly engage in farm and off-farm labor work, repair work, carrying loads, etc. Migration is mostly of male members from both communities from the village to nearby towns or cities in search of higher income livelihood options. Womenfolk from the resident families perform most of the agricultural activities as well as domestic activities. Water is supplied through municipal tanks sourced from the River Alaknanda under a water lift pumping scheme called the Bhagwan scheme (Bhadwal *et al*., 2017). Women fetch water from community taps (stand posts) distributed within the village supplying water under this scheme.

Study approach and methods

The present research uses the case study approach (Yin, 1994). All the case sites are exposed to either a situation of water scarcity or flooding. The following research questions were laid down before initiating the field research:

> '*RQ1. What is the nature of settlement of the community and the surface/groundwater bodies in the study site? How the water bodies are spatially distributed? And, what is the relationship between communities and water bodies in their area in terms of associated water-related hazards?*
>
> *RQ2. What are the attributes of the identified hazard associated with water bodies? How are these attributes leading to differential exposure to hazards?*
>
> *RQ3. How these differential water-related hazards have been addressed by the community?*'

The methodology of the study has been designed (Figure 1(b)) to bring community participation, research and technology together for social learning research. With the integration of PRA, which facilitates the participation, and PGIS, which helps in creation of technically advanced data and spatially specific research, this methodology draws upon all the above-mentioned aspects. The new knowledge gathered from these important aspects is integrated to develop maps which can be utilized by the people of the communities and policy makers to assess the hazard situation. These maps can be used as adaptive planning maps of the region.

Various aspects of the context were discussed and arrived at using the different set of tools of PRA (Table 2). *Transects* were conducted within the study area to become familiar with the general setting of

Table 2. Research tools used to understand water hazard at study sites.

Area	Semi-structured interview Key informant interviews	Group discussions	PRA tools
Hakimpur Turra	5 (1 F). 10 M and 4 F with key informants from a different ethnic background in the village, 2 (M, F) with an expert from NGO Mount Valley Development Association and Tara Akshar working in the area	Five groups (one with women)	One resources map One timeline Five transect walks and direct observations One PGIS map from the cadastral map
Khadri Kharak Maf	3 (all with key informants) (Elder *Buksa* fisherman and farmer (M), Town council head (M), Middle-aged man who participated in the previous study on the *Buksa* tribe (M)	Three groups (one with women)	One resource Map One timeline Two transect walks and direct observation One flood zoning map with Google map
Kimkhola	4 (all with key informants) Village council head – *Pradhan* (M), Elderly former *Pradhan* in the village (M), Anganwadi worker (F)	Three groups (one with women)	One resources map Two timelines Two transect walks and direct observation One PGIS map from the cadastral map

M, male; F, female.
Adapted from Al-Qubatee *et al.* (2017).

the sites and to be introduced to the residents (Geilfus, 2008, Chapter 4: Participatory Appraisal: Natural Resource Management, p. 65). It was also to observe attributes of research interest within the social habitation of the village including the placement of water resources. These observations were used as early illustrations and the features were recorded in a hand-drawn map to be used as a starting point for initiating discussions. Residents from various age groups were involved to record important series of events in the study areas such as the occurrences of droughts, floods, depletion in the groundwater table, and observed reduced discharge in river and springs in a *timeline exercise*. Elderly people were involved in the exercise to record historic events in the village (Geilfus, 2008, Chapter 3: General Community Issues/Social Issues, p. 53). *Hazard mapping/flood zonation mapping* was carried out with older members (>50 years) of the *Buksa* community to demarcate the extent of flood flows of any major flood event and changes in river morphology, over the last 60 years. This activity was conducted in the context of three major periods related to the changes in river geo-morphology that emerged out of discussions – before barrage, after barrage, and after the major flood event in the year 2013 in the state. A *time trend* chart was drawn with communities to depict the changes in the quantum of water resources (groundwater level and spring) over the years and consequential changes or impacts on associated activities of people. This helped to understand the variation in water accessibility and availability for domestic and agricultural purposes with the changes in the geography, socio-ecological conditions/ climate.

Finally, after collecting all the necessary background information, the PGIS exercise was initiated by acquiring cadastral maps procured from Land Revenue Departments of various block offices in the region. The focus was on understanding the spatial nature of various attributes of interest emerging from previous discussions in the study areas. For example, the extent of the inundation of the river during floods, location, and area of farms, springs, and the location of various water access points (pumps, stand posts) were recorded on the map. These village-level cadastral maps were digitized using ARC GIS (10.2.2) and geo-referenced with GPS points taken from the village. These digitized maps with recorded attributes, which were to scale, were taken to the community again to cross-check the positioning of attributes and initiate a detailed discussion surrounding the pertinent issues. A stepwise procedure of this activity is shown in Figure 1(c).

In addition, key informant interviews were conducted with officials at local water supply and management departments to engage them in building up the knowledge base as well as triangulating the field data. Throughout our discussions, questions were largely kept open-ended and as mere pointers to start the conversation and facilitate emergence of newer perspectives. Focused group discussions were also conducted with different ethnic groups, men and women residing in the villages, to remove any bias in perspectives owing to inherent social strata and existent power dynamics.

Analysis and results of participatory GIS mapping

Focusing on the essential components of the PGIS exercise (spatial specificity, social inclusion, and environment for social learning) and the aim, the three selected cases were mapped independently to determine robustness of the methodology within different natural landscapes and social dynamics (proximity, availability, and access). In this section, the results of the integrated social and spatial database prepared using PRA and PGIS for different cases is presented.

Case 1: Uncovering groundwater availability and differential access in Hakimpur Turra village

The socio-economic set-up in the village is mostly a reflection of the caste system which has existed for generations. In Hakimpur Turra, large sections of the land are still owned by the affluent caste that is comparatively wealthy, while people belonging to the SC community own less land per capita and work as agricultural laborers on the lands of large farmers. Farming is entirely irrigated using groundwater, which is available variably, according to the topography of between 50 and 250 ft depth (1 ft = 0.305 m). Water is pumped using bore wells. The land ownership largely governs crop choices and access to groundwater. Large farmers (with more than 50 bighas' land area; bigha = 2,500 square meters) mostly engage in a monoculture pattern of growing water-intensive crops – sugarcane, paddy, and eucalyptus and poplar plantations.

To achieve enhanced participation through a neutral mapping tool, the map was taken to different settlements within the villages and used as an entry point to initiate discussions around specific contexts. The mapping exercise reveals that ownership of private boring pumps lies largely with the well-off OBC communities while others (SC group) either depend on neighbors for irrigation or fetch water from common water points set up by the government for domestic purposes. Large farmers have private borewells in their fields to pump water, whereas medium (50–10 bigha) and smaller farms (<10 bighas) are irrigated through rented water from large farmers or using water from government installed borewells. Even in the case of water for domestic consumption, OBC farmers have mostly private submersible pumps dug beyond 55 ft depth, as water quality is not perceived to be appropriate at depths less than 55 ft. Analysis of the PGIS maps, timeline, and time trend exercise show, even though it appears that there is plenty of groundwater available for everyone to tap into for irrigation and drinking purposes, groundwater levels have been declining in the area.

Further social learning was achieved by integrating the knowledge gained from community-based discussions with existing literature as well as understanding of the government officials of the area. For example, the declining trends of groundwater were substantiated when key informant interviews (KII) with officials at Central Ground Water Board (CGWB) showed that before the year 2010, Bhagwanpur block was put in the category of an 'overexploited' zone as per their classification. The map also shows a high tube-well density causing a localized large-scale extraction of groundwater which is likely to cause an inordinate delay in the recovery of the water levels in all the wells based on the concept of zone of influence in groundwater hydrology. In fact, the National Bank for Agricultural and Rural Development (NABARD) gives prescriptions to maintain a minimum distance of 300 m (ARDC, 1979) between tube-wells in alluvial aquifers in an area with annual average rainfall of 1,170 mm, similar to conditions prevalent in the study area as shared by one of the officials in the irrigation department during KII. Taking this as a reference and by creating buffer zones of 300 m around each access point on the map, it was found that there are many 'zones of influence' (*the land area above the cone of depression of a well which contributes groundwater to the production well*) overlaps (Figure 2), which must lead to a cumulative draw-down effect and shortage of water in shallow wells. To reiterate, shallower wells typically belong to poorer SC households. Clean drinking water available at more than 200 ft has a very high cost of extraction (the cost of installing a submersible pump is INR 2,00,000) and hence only the well-off OBC farmers can afford to install it. Thus, there is a stark inequity in access to groundwater, which is coming to light through this analysis. Also, any further depletion in groundwater in future climate change scenarios will not only make the extraction more expensive and energy intensive but will also broaden the prevalent inequity in water access.

Currently, for ensuring continuous access of water for agriculture with declining trends, pumping with even higher rigor seems to be the solution adopted in the area. Farmers have resorted to digging deeper tube-wells for readily available water as a coping strategy. In the wake of the River Solani's drying riverbed, even floodplain (*paalej*) farming for vegetables is carried out by pumping groundwater using tube-wells. Two very deep (>600 ft) government tube-wells have also been set up in the village for irrigating farms belonging to people from the SC community who had no private connections of their own. The 'double boring' connection (two bores are made in close proximity to increase water output) is also sought to overcome the groundwater access problem. To access clean drinking water, new hand pumps have been set up at depths greater than 200 ft by all families from the OBC community but residents of the SC community still rely on shallow pumps or common government pumps. They fetch clean water from these common pumps or sometimes even borrow water from OBC households. However, during the course of research and information sharing, a handful of farmers are seen to move towards solutions to cut down their demand, for example, switching to less water-intensive crops. Chana (chickpea) crop in the village is being grown by one of the farmers. According to him, it is a crop which can be grown without any irrigation. More alternative and demand management solutions emerged during the discussions after the map showing 'zone of influence' overlaps was taken back to the community. There is a traditional water harvesting pond (currently defunct) in the village and the current female Pradhan suggests reviving the structure to have a freshwater reserve in the event of any significant reduction in groundwater level. Later, these solutions from the community were also taken back and discussed with concerned officials and planners who were made aware of the alternative solutions, other than digging deeper borewells, to meet water demand.

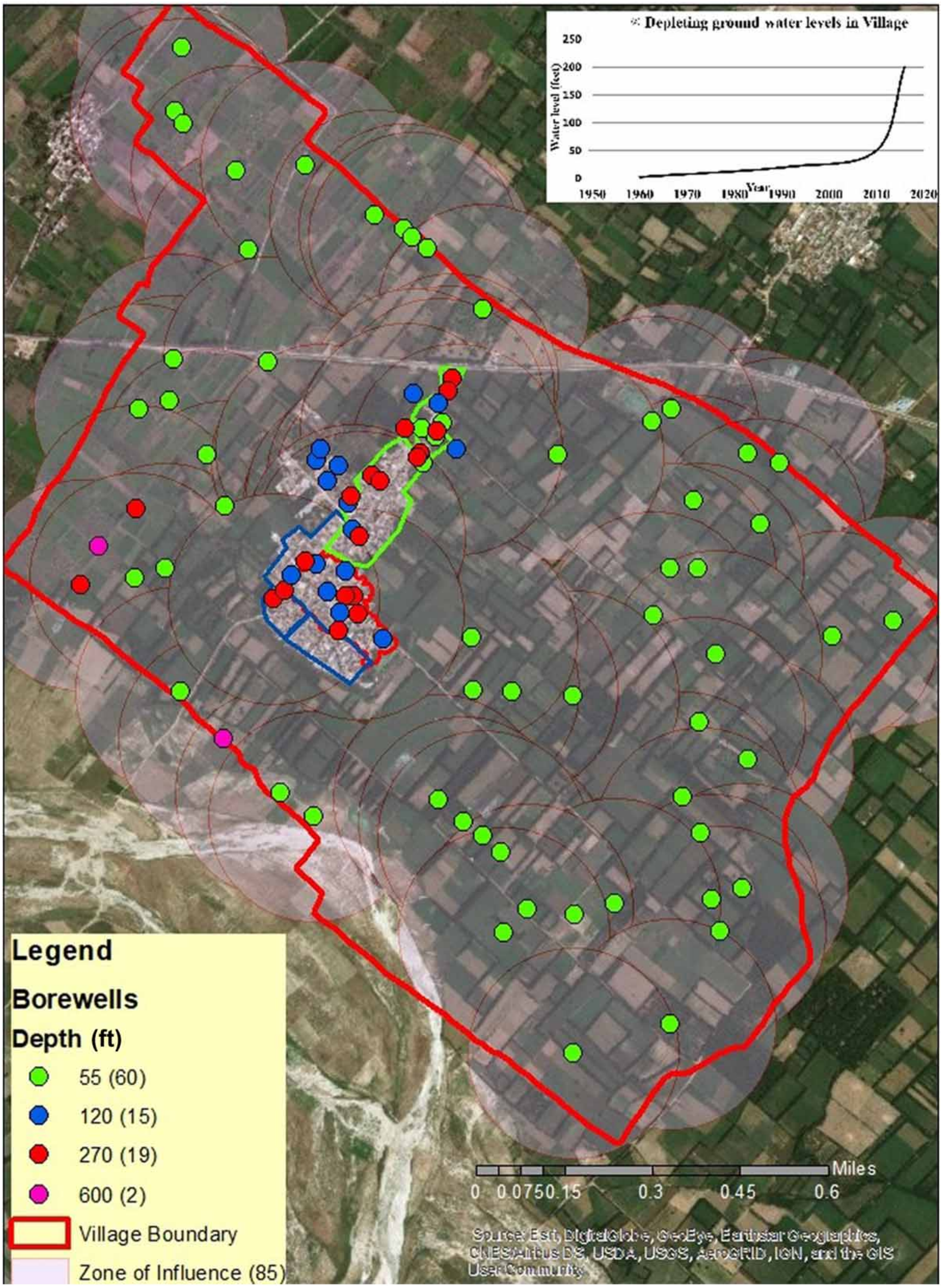


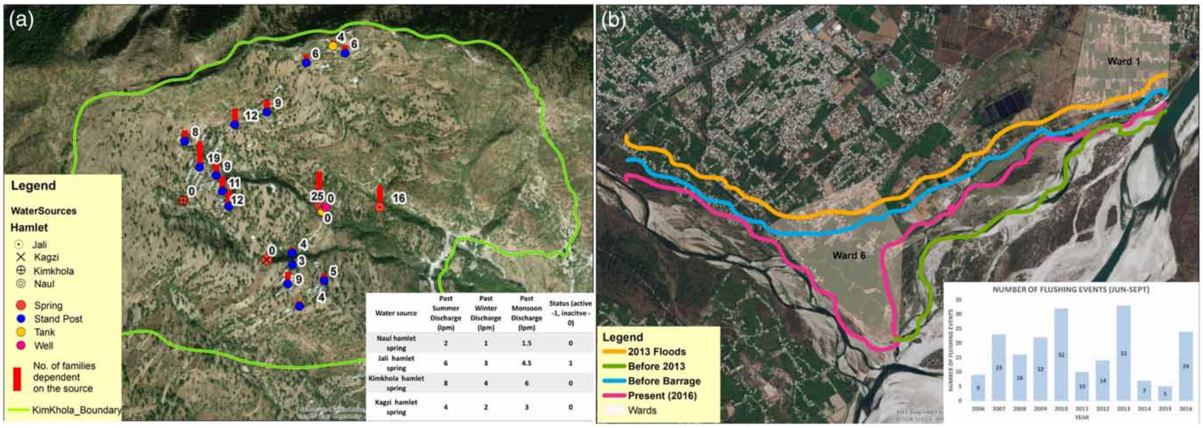
Fig. 2. Hakeempur water access points (total of 419 small hand pumps in every household not shown). Buffer analysis: zone of influence overlaps. Graph: depleting groundwater trend. (*Source*: field work, time trend PRA, 2016).

Case 2: Understanding differential hazard and impacts of flooding in Khadri Kharak Maf

There are about 114 *Buksa* tribe families that reside in ward number 6 of Khadri town. The rest of the settlement has *Garhwali* families as the major community group. However, analysis of timeline charts made along with the community showed that the area was originally inhabited entirely by *Buksas*, and the *Garhwali* community came to this area much later. Being nomadic in nature, *Buksas* initially practiced fishing in the river and slowly started to cultivate the land. *Garhwalis* were allotted land in the town by the government around the year 1965. At this time, some of the *Buksa* families sold off their remaining land due to 'urgent' need of money for family weddings and some land was also 'occupied by force', but they do not have any legal rights over the land. The Lakarghat (Ward 1) (Figure 3(a)) area has agricultural fields, where sugarcane and paddy are mainly grown. The agricultural land closer to the river is farmed by *Buksas* who cultivate millet, pulses, and vegetables.

To trace the hazard posed by the flood regime of the rivers Ganges and Song, in a more holistic and inclusive way, discussions were held and mapping was done with the riparian *Buksa* communities living in the town for generations. Currently, of the different ethnic groups residing in the area, the livelihoods of members of this tribe are most affected by flooding. Analysis of the map and subsequent discussions held within the *Buksa* community reveal that the river course has moved significantly away from the settlement area after construction of the barrage in the 1970s. *Buksas* now live on land closest to the river's main channel, which gets flooded, but no crop compensation can be claimed for the damages accrued, due to lack of any legal land ownership. Since the Ganges is also dammed (with Veerbhadra barrage) upstream of this village, flood flows are controlled and are now perceived by residents as 'gate opening events' from the barrage (Figure 3(a)).

In the 2013 flood event, most of the standing crops of the *Buksas* were destroyed and they had to evacuate their houses as water from the Ganges inundated their area. Pointing out the dampened walls because of flood water reaching their settlement, a 60-year-old tribal couple explained:



Water source	Past Summer Discharge (lpm)	Past Winter Discharge (lpm)	Past Monsoon Discharge (lpm)	Status (active -1, inacitve - 0)
Naul hamlet spring	2	1	1.5	0
Jali hamlet spring	6	3	4.5	1
Kimkhola hamlet spring	8	4	6	0
Kagzi hamlet spring	4	2	3	0

Fig. 3. (a) Map showing flood inundation area and wards of Khadri Khadag Maf (resource map exercise, summer, 2017), flushing events versus time (*source*: field interview 2016 and records at Veerbhadra barrage office); (b) Kimkhola village water resource map, village spring sources, and changing discharge (*source*: seasonal calendar, field work, October 2016).

> '*Earlier we knew how to live with the pulse of the river. Our settlements were away from the reach of the river and we would not dare go near her during monsoon. Now we do not know how the river will act*.'

This knowledge of their memories of the river flow regime received from riparians was integrated with information received from barrage managing officials. Interviews were conducted with officials at Veerbhadra barrage and records of both flooding and flushing events at the barrage operations during the monsoon season from 2006 to 2016 years were noted and studied (Figure 3(a)). This corroborates the memories of flood events when recalled under the timeline exercise conducted with the participants in the town.

By mapping flood zones temporally (Figure 3(a)) onto a digitized to-scale map (PGIS), an objective understanding of the flood emerged. Through discussions of flood inundation zones, it was discovered that flood flows were of a different nature before and after the barrage construction. Due to the construction of the barrage, the main channel was moved away from the settlement. *Buksas* who were living away from the channel moved closer to the main channel in view of the existing picture of floods. In the lack of awareness, recognition of their rights, and claim on the land ownership, they now live in a dilemma and at constant risk of flooding in the case of extreme events, whose frequency and magnitude are predicted to rise with climate change.

In the case of flooding in the Song River, flood water has historically inundated the fields up to 5–5.5 ft in height and stood in the fields for up to 2 days. A 10 ft high embankment was built to avoid spreading of river water in 2008–2009. This has helped in stopping 'toe-cutting' and erosion of the fields of the Garhwali community or the later settlers in the area, so it works well for this section of the society.

However, when asked whether the embankment is seen as one of the possible ways to flood proof the area and hence cope with flood hazard in Ganga, a respondent from the *Buksa* community said:

> '*It won't solve the problem for our community. Either rehabilitate us and provide fertile agricultural land away from this area or make some provision so we could also claim compensation in events of crop losses*.'

Since they do not own the land legally, *Buksas* are unable to claim any compensation distributed during flood relief drives by the disaster management department. The *Buksa* community believes the best way to cope with the situation is to relocate to a place with no hazard. Thus, this exercise helped us as researchers to see through the interventions, such as embankment in this case, and ask the question, who does it really work for? The insight received, that the intervention is not solving the purpose of flood risk reduction for all sections of society, was taken up further with the disaster relief officials at district level to make them aware of the situation.

Case 3: Spring and water access mapping in Kimkhola

During the PRA exercise in Kimkhola village, non-uniformity of landholding was brought to light, similar to previously discussed cases of Hakimpur village. Traditionally, the SC community has a lesser share of land than the *Rajput Garhwali* community. Less land ownership has led many SC families to either engage in off-farm activities like masonry, repair work, and on- or off-farm labor.

All *Rajput Garhwali* families (65% of village population) earn their living through farming activities, government, and private jobs. They reside within the main settlement area, where all active spring sources are located. The SC community was allotted houses under Indira Awas Yojana: a government housing scheme for marginalized people, near the village periphery, but houses do not have any water connection (field observation, 2016).

In the mapping (PGIS) exercise, villagers identified four springs in their village, of which only one is active presently. They also mapped municipal water tanks and stand posts within the village. Figure 3(b) gives the details of these springs, tanks, and stand posts. Residents mentioned reduced discharge in all four springs with some even completely drying up in the lean season. Deforestation in the catchment and increasingly erratic rainfall with climate change have been affecting recharge of groundwater leading to drying up of water sources. The area was faced with a severe water crisis around 40 years ago, and the crisis became so acute that the residents resorted to campaigning to seek the water department's attention for a solution to water availability in their area. In an oral history exercise, an 80-year-old male interviewee reported that the issue was resolved by supplying water by linking the villages to Bagwan water pumping scheme in the area, sourcing water through lift pumping from Alknanda river.

Mapping of water access points revealed that water access is not homogenous in the village. In Kimkhola, there are two separate tanks built for water distribution (Figure 3(b)) for *Rajput Garhwali* and SC community households. There are around 14 stand posts for 115 families of the *Rajput Garhwali* community, supplying water from municipal tanks. However, in the absence of any distribution network for the SC community, women of this community walk up to the tank to fetch water for their families. They make two to three trips in a day and spend almost 2–3 hours collecting water. In summers, due to a rise in overall water demand, the supply becomes intermittent and fails to meet the water requirements. Moreover, during monsoons, breakage in pipelines leads to a supply with poor water quality, which is when residents prefer spring water for drinking and cooking purposes. Spring discharge increases comparatively during the monsoon season but still does not meet the overall demand. Also, as revealed during the mapping exercise, there is only one active spring during the lean season and two during monsoons. The SC community has limited access to both these springs. In events of crisis, women invest nearly double the time to fetch water from a government hand pump installed outside the village boundary, about 4 km away from their settlement. The distance to the water resource was also validated through precise spatial mapping of water access. Currently, amidst reduced accessibility to existing spring water sources within the village, SC families feel vulnerable to municipal water supply cut-off, especially considering the drudgery faced for its collection. Multiple water sources mean *Rajput Garwali* communities are less vulnerable regarding water access and availability.

At present, water demands are met through public water supply which is pumped from the river. Although additional water supply from the river has increased water availability in the village, it has also increased the dependence of villagers on an external source of water. This mechanism, to meet water demand, is not a sustainable solution as it is energy intensive and takes away community control over their water resource. When the springs were active, the community used to take care of them as a common property resource. A community-level governing body was responsible for the maintenance of the water recharge zone and water harvesting structures for better water supply in the village. Also, springs maintained the micro-climate and enhanced vegetation growth in the region. Spring water is of higher quality, as being underground, its quality is maintained throughout the year. In contrast, river water quality changes with the season and silt load. Little focus on effective implementation of spring revival programs and availability of municipal water supply at the doorstep has shifted focus away from active community participation in ecological restoration initiatives. Instead, the focus has shifted to cater for the water demand through hard infrastructural measures. Realizing the fact that even the public water supply does not contribute to water security in the village, under *Gram panchayat*'s initiative, the *Gram Pradhan* (village head) has undertaken the restoration of springs in the village to revive in-house sources of water that will always be available within the village when the municipal supply is disturbed. During the study, this initiative resonated with the community as they understood that total dependence on river water pumping might leave them at greater risk than having their own local source of water, especially with risks of high intensity rainfall damaging pipelines more often than in the past.

Discussion and conclusion

The nuanced narratives captured spatially using PGIS in this study give a unique entry point for science–community dialogue, increase participants' engagement due to the visual dataset, and create knowledge products for the concerned stakeholder community to use. Table 3 illustrates the usefulness of various tools for contextual risk analysis research and highlights that the participatory GIS mapping technique has been effective in attaining the objectives, in terms of spatial specificity, social inclusion (participation), and social learning.

Maps created through traditional PRA cannot quantify the spatial specificity that is easily achieved through PGIS. The exact attributes like latitude, longitude, and elevation of the feature are marked during the exercise. As shown with the above case studies, the maps created using PGIS served as tools to capture the multi-disciplinary information. They not only preserved co-created, to-scale, detailed spatial information, but were also further enriched with newer secondary information attributes obtained from other resources such as government departments, to present a complete picture of the complex

Table 3. Usefulness of methodology.

Objectives						
Tools	Water availability/Water access	Hazards	Social dynamics	Spatial specificity	Social inclusion (participation)	Social learning/ Capacity building
KII and semi-structured inteviews	++++	++++	++++	−	+++	++
Transect walk and direct observation	+++	++	++	−	+++	++
Timeline and time trend	++	++	+	−	++	+++
Focused group discussion	++++	++	++++	−	++	+++
PGIS maps	+++++	++++	+++++	+++++	+++++	+++++

Notes: Many plus signs (+) mean the strong contribution of the method to the achievement of the objectives.
Adapted from Al-Qubatee *et al*. (2017).

issue. The use of PGIS also provided a wider platform for incorporating inputs from different socio-economic and socio-cultural groups within the communities, catering to social inclusion.

In Kimkhola, taking the cadastral village map to participants became a good entry point activity which made it much easier to win people's trust as it showed extensive preparation, and a serious commitment to understand the current situation and to look for possible solutions from the researcher's side. It also helped in involving communities to actively participate and share their knowledge as well as to have a discussion on future hazard scenarios rather than being passive onlookers. As the methodology calls for showing the land revenue map to the villagers, the enthusiasm to locate the water resources was perceivably higher as compared to a mundane resource mapping in PRA. Although the methodology required more preparation off-field, the work on-field became much faster and precise, in terms of orientation and output. Thus, it was evident that the PGIS exercise created an environment of social learning.

Hakeem turra is a comparatively large village in terms of its population, geographic area, and diverse ethnic groups. Incorporating concerns from all the sub-groups was a challenge. Again, the cadastral map became a great platform for building community trust. Many points which were not so obvious during FGDs emerged organically as participants got deeply involved during the PGIS activity. For example, the insight that socio-economically well-off large farmers can spend more money and dig deeper with a declining water table, thus increasing competition for small marginal farmers, was not evident earlier until the pumps that were marked on the residents and PGIS maps showed the zone of influence areas' overlap. Through a shared understanding of well interference, it became essential to perceive that rights to groundwater are correlative. The magnitude of water exploitation by one farmer affects the neighboring farmer's ability to utilize groundwater effectively. Discussions through a visual display of information became key to understanding the *overdraft* problem and necessity of a village level groundwater regulatory and management system. Moreover, all the sub-groups in the village agreed that collective action is required to create/revive existing rainwater harvesting structures in the village and reduce dependence on groundwater.

This methodology also gave researchers an opportunity to exchange knowledge of the hydrological sciences and technical scientific knowledge about the water resources and nature of floods in the sites, thus opening up an environment for social learning and collective action. For example, in the case of *Khadri Kharak Maf*, it was validated through published research how structures on the river can alter the geomorphology of the river, confusing communities' memory of natural flood flows (Krause, 2010). This information built awareness and capacity of not only the communities but also of the government officials with whom maps were shared under separate consultations to enable bottom-up planning and participation regarding management of water resources.

In all case study sites, it was observed that when the maps prepared by the community were shown to them, they (especially the marginalized ones) became more confident of their knowledge and understanding of water resources and assets/infrastructure in their vicinity, prompting them to participate in decision-making. Table 1 also summarizes the understanding about the water-related hazard situation in the study areas.

In the end, the entire process of map creation made different stakeholders aware of the importance of knowledge integration at each level for achieving mindful coping strategies which serve a purpose for everyone. In turn, the exercise built everyone's capacities to deal with hazards and adapt in a more participatory way. As a result, the richness of information motivated them to diversify the coping strategies and come up with more soft, nature-based solutions to enhance the resilience of riparian communities against various water stress situations. For example, the bore well information in one of the case study villages can act as a baseline to place extraction points for sustainable water use. Water depth of these wells can be marked yearly and added to the map to understand the local fluctuations and to have better water management plans. Moreover, these maps can also highlight if any focal area needs special attention. For instance, during the research, villagers highlighted that few of the bores used for irrigation have been replaced by submersible pumps as more energy is required to extract water from deeper aquifers. The authors believe that maps created through PGIS can continue to serve as a platform for communication among all the sub-groups in the community and prepare them for future hazards emerging with changing climate.

Acknowledgement

This study is a part of the Himalayan Adaptation, Water and Resilience (HI-AWARE) consortium under the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA) – a research program supported by the UK Government's Department for International Development (DFID) and Canada's International Development Research Centre (IDRC). The study was undertaken by TERI School of Advanced Studies and The Energy and Resources Institute (TERI). The views and opinions in the paper are solely those of the authors. The authors are grateful to the all the villagers, sponsors, and TERI's operational partner CEDAR, Uttarakhand.

References

Agricultural Refinance and Development Corporation (ARDC) (1979). *Report of the Groundwater Over-Exploitation Committee*. Bombay, India, p. 93.

Al-Qubatee, W., Ritzema, H., Al-Weshali, A., van Steenbergen, F. & Hellegers, P. J. (2017). Participatory rural appraisal to assess groundwater resources in Al-Mujaylis, Tihama Coastal Plain, Yemen. *Water International 42*(7), 810–830.

Awais, M. & Khan, N. (2014). Adoption of new agricultural technology: a case study of Buksa tribal farmers in Bijnor District, Western Uttar Pradesh, India. *International Journal of Agriculture, Environment and Biotechnology 7*(2), 403–408.

Bebbington, A. (2000). Reencountering development: livelihood transitions and place transformations in the Andes. *Annals of the Association of American Geographers 90*(3), 495–520.

Bhadwal, S., Ghosh, S., Gorti, G., Govindan, M., Mohan, D., Singh, P. & Yogya, Y. (2017). *The Upper Ganga Basin–Will Drying Springs and Rising Floods Affect Agriculture*. HI-AWARE Working Paper 8. Kathmandu, Nepal.

Chambers, R. (1994). The origins and practice of participatory rural appraisal. *World Development 22*(7), 953–969.

Chingombe, W., Pedzisai, E., Manatsa, D., Mukwada, G. & Taru, P. (2015). A participatory approach in GIS data collection for flood risk management, Muzarabani district, Zimbabwe. *Arabian Journal of Geosciences 8*(2), 1029–1040.

Cho, C., Li, R., Wang, S. Y., Yoon, J. H. & Gillies, R. R. (2016). Anthropogenic footprint of climate change in the June 2013 northern India flood. *Climate Dynamics 46*(3–4), 797–805.

Department of Science and Technology (DST) (2017). *Inventory of Revival of Springs in Himalayas for Water Security*. Ministry of Science and Technology, Government of India. Available from: http://www.dst.gov.in/sites/default/files/NITI-Aayog-report-Springs-29Dec2017-FINAL.pdf

Elwood, S. (2009). Multiple representations, significations, and epistemologies in community-based GIS. In: *Qualitative GIS: A Mixed Methods Approach* (Cope, M. & Elwood, S., eds). Sage, Thousand Oaks, CA, USA, pp. 57–74.

Geilfus, F. (2008). *80 Tools for Participatory Development: Appraisal, Planning, Follow-up and Evaluation (No. 303.4 G312e)*. IICA, San José, CR.

GOI (2011). *Census of India 2001*. Ministry of Home Affairs, Government of India, New Delhi, India.

Immerzeel, W. W., Van Beek, L. P. & Bierkens, M. F. (2010). Climate change will affect the Asian water towers. *Science 328*(5984), 1382–1385.

International Institute for Environment and Development (IIED) (2009). *Profiles of Approaches, Tools and Tactics for Environmental Mainstreaming Participatory Geographical Information System*. IIED, London, UK.

Jankowski, P. (2009). Towards participatory geographic information systems for community-based environmental decision making. *Journal of Environmental Management 90*(6), 1966–1971.

Khan, S., Sinha, R., Whitehead, P., Sarkar, S., Jin, L. & Futter, M. N. (2018). Flows and sediment dynamics in the Ganga River under present and future climate scenarios. *Hydrological Sciences Journal 63*(5), 763–782.

Krause, F. (2010). *Thinking Like A River: An Anthropology of Water and its Uses Along the Kemi River, Northern Finland. Doctoral dissertation*, University of Aberdeen, UK.

Kulkarni, H. & Thakkar, H. (2012). 24 framework for India's strategic water resource management under a changing climate. In: *Handbook of Climate Change and India: Development, Politics and Governance*. Dubash, N. K. (ed.). Earthscan, Abingdon, UK, p. 328.

Kumar, M. D., Patel, P. & Moench, M. (1994). *Participatory Mapping as A Diagnostic Tool for Groundwater Studies*. Monograph. VIKSAT, Ahmedabad, India.

Kumar, M. D., Scott, C. A. & Singh, O. P. (2013). Can India raise agricultural productivity while reducing groundwater and energy use? *International Journal of Water Resources Development 29*(4), 557–573.

Maguire, D., Goodchild, M. F. & Rhind, D. W. (1991). *Geographical Information Systems*. Longman, London, UK.

Maplecroft (2011). *World's Fastest Growing Populations Increasingly Vulnerable to the Impacts of Climate Change – 4th Global Atlas Reports*. Available from: http://maplecroft.com/about/news/ccvi_2012.html

Ministry of Water Resources (MoWR) (2009). *Comprehensive Mission Document of National Water Mission Under National Action Plan on Climate Change*, Vol. 1 and 2. Government of India, New Delhi, India.

Mosse, D. (1995). Authority, gender and knowledge: theoretical reflections on participatory rural appraisal. *Economic and Political Weekly 30*, 569–578.

Mukherjee, A., Saha, D., Harvey, C. F., Taylor, R. G., Ahmed, K. M. & Bhanja, S. N. (2015). Groundwater systems of the Indian sub-continent. *Journal of Hydrology: Regional Studies 4*, 1–14.

Muthuwatta, L. P., Bos, M. G. & Rientjes, T. H. M. (2010). Assessment of water availability and consumption in the Karkheh River Basin, Iran – using remote sensing and geo-statistics. *Water Resources Management 24*(3), 459–484.

Negi, G. C. S. & Joshi, V. (2002). Drinking water issues and development of spring sanctuaries in a mountain watershed in the Indian Himalaya. *Mountain Research and Development 22*(1), 29–31.

Nyerges, T. L. (1993). How do people use geographical information systems. In: *Human Factors in Geographical Information Systems*. (Medyckyj-Scott, D. & Hearnshaw, H. M., eds). Halsted Press, New York, USA, pp. 37–50.

Pahl-Wostl, C. (2007). Transitions towards adaptive management of water facing climate and global change. *Water Resources Management 21*(1), 49–62.

Rodell, M., Famiglietti, J. S., Wiese, D. N., Reager, J. T., Beaudoing, H. K., Landerer, F. W. & Lo, M. H. (2018). Emerging trends in global freshwater availability. *Nature 557*(7707), 651–659.

Sati, V. P. (2005). Systems of agriculture farming in the Uttranchal Himalaya, India. *Journal of Mountain Science 2*(1), 76–85.

Scott, C. A. & Shah, T. (2004). Groundwater overdraft reduction through agricultural energy policy: insights from India and Mexico. *International Journal of Water Resources Development 20*(2), 149–164.

Scott, C. A. & Sharma, B. (2009). Energy supply and the expansion of groundwater irrigation in the Indus-Ganges Basin. *International Journal of River Basin Management 7*(2), 119–124.

Tambe, S., Kharel, G., Arrawatia, M. L., Kulkarni, H., Mahamuni, K. & Ganeriwala, A. K. (2012). Reviving dying springs: climate change adaptation experiments from the Sikkim Himalaya. *Mountain Research and Development 32*(1), 62–72.

Tripathi, N. & Bhattarya, S. (2004). Integrating indigenous knowledge and GIS for participatory natural resource management: state-of-the-practice. *The Electronic Journal of Information Systems in Developing Countries 17*(1), 1–13.

Valdiya, K. S. & Bartarya, S. K. (1989). Diminishing discharges of mountain springs in a part of Kumaun Himalaya. *Current Science Bangalore 58*(8), 417–426.

Weiner, D., Warner, T. A., Harris, T. M. & Levin, M. R. (1995). Apartheid representation in a digital landscape: GIS, remote sensing and local knowledge in Kiepersol, South Africa. *Cartography and Geographic Information Systems 22*(1), 30–44.

Whitehead, P. G., Barbour, E., Futter, M. N., Sarkar, S., Rodda, H., Caesar, J. & Salehin, M. (2015). Impacts of climate change and socio-economic scenarios on flow and water quality of the Ganges, Brahmaputra and Meghna (GBM) river systems: low flow and flood statistics. *Environmental Science: Processes & Impacts 17*(6), 1057–1069.

Yin, R. K. (1994). Case Study Research: Design and Methods (2nd ed.). Sage, Beverly Hills, CA.

Zanetell, B. A. & Knuth, B. A. (2002). Knowledge partnerships: rapid rural appraisal's role in catalyzing community-based management in Venezuela. *Society & Natural Resources 15*, 805–825. doi:10.1080/08941920290107576.

Received 11 February 2019; accepted in revised form 9 July 2019. Available online 4 September 2019