Application of Modelling to Investigate Irrigation Conflicts Between Small Farmers of Barabarahi, Nepal (#494)

Application of Modelling to Investigate Irrigation Conflicts Between Small Farmers of Barabarahi, Nepal

Authors:
Mr. Laurent-Charles Tremblay Lévesque – Integrated Water Resources Management Advisor
Nepal Agricultural Central Cooperative Federation Ltd. (NACCFL)
Mr. Neem Lal Pandey – Agricultural Specialist, NACCFL
Mme Meena Pokhrel – Senior Program Officer, NACCFL

Editors:
Mr. Kenge James Gunya – Knowledge Management Officer: GWP Global Secretariat

This case study is submitted by GWP partner. The views expressed in this case study do not necessarily represent the official views of NACCFL.

May 2018

www.gwp.org/ToolBox

About Global Water Partnership

The Global Water Partnership's vision is for a water secure world. Our mission is to advance governance and management of water resources for sustainable and equitable development.
GWP is an international network that was created in 1996 to foster the implementation of integrated water resources management: the coordinated development and management of water, land, and related resources in order to maximize economic and social welfare without compromising the sustainability of ecosystems and the environment.

The GWP Network is open to all organizations that recognize the principles of integrated water resources management endorsed by the Network. It includes states, government institutions (national, regional, and local), intergovernmental organizations, international and national non-governmental organizations, academic and research institutions, private sector companies, and service providers in the public sector.

The Network has 13 Regional Water Partnerships, 85 Country Water Partnerships, and more than 3,000 Partners located in 182 countries.

Global Water Partnership (GWP), Global Secretariat, PO Box 24177, 104 51 Stockholm, Sweden
Phone: +46 (0)8 1213 8600, Email: gwp@gwp.org, Facebook.com/globalwaterpartnership, Twitter@gwpnews

About NACCFL

The Nepal Agricultural Cooperative Central Federation Ltd. (NACCFL) is an umbrella organisation of 915 Small Farmers Agricultural Cooperatives (SFACL). NACCFL's network covers 71 of the 77 districts of Nepal and represents a total of approximately 860,000 small farmers.

NACCFL aims at providing appropriate financial and non-financial services to all the member organizations for their institutional development and for the socio-economic development of the deprived small farmers across the country. Its objectives can be grouped in three categories: (1) capacity building; (2) policy advocacy and; (3) cooperative network expansion.

Nepal Agricultural Co-operative Central Federation Ltd.
Bakundole -3 , Lalitpur, Nepal
Tel. No.: +977-01-5528073/5528074
Fax No.: +977-01-5528074
E-mail: skbks.nepal@gmail.com
Website: https://www.naccfl.org.np

The views expressed in this case study do not necessarily represent the official views of NACCFL

Table of Contents

1. Background

The Bajrabarahi Village Municipality is situated in Makwanpur District, Province No 3, about 50 kilometres southwest of Kathmandu. As of 2011, it had 1,630 households for a total population of 7,675 (CBS, 2014). Bajrabarahi is a predominantly agricultural community with small commercial activities as well (e.g. restaurants, convenience stores, hardware and mechanic shops). Agriculture wise, the area is renowned for its off-season production during winter and spring. Its products are mostly sold in the markets of neighbouring towns such as Markhu, Chandragiri and Dakshinkali. Some farmers also manage to sell their harvests, generally higher value horticultural crops, in markets across the Kathmandu Valley.

The climate of Bajrabarahi is typical to what is found in any other hilly zones of southern Nepal (Figure 1). The summer months are warm and moist with average relative humidity maintaining itself over the 80% mark from June to September (DoHM, 2018). Temperature and humidity considerably drops during the winter months. The night time temperatures can fall below 0 °C from December to February but day time temperatures can easily reach above 20 ℃. The average precipitation in Bajrabarahi, 1747 mm/year, is relatively high for Nepal. Kathmandu, in comparison, receives 1343 mm/year (DoHM, 2018). The distribution of the rainfall conversely follows the same unimodal pattern which affects all of Nepal and which is centred around the monsoon season. Eighty-six percent of the annual rainfall which Bajrabarahi receives happens between the months of May to September (DoHM, 2018).

The village centre sits at approximately 1700 m a.s.l. and is surrounded by mountains going up to 2300 m a.s.l. Most of the land cover is occupied by agricultural land but the uphill areas are still predominantly forested (Figure 2). The community is thus gifted with abundant natural water resources as several forest born springs run from the mountains into the agricultural lands. Canals for irrigation purposes were built to divert both seasonal and perennial springs. Mr. Maheshwor Subedhi, Chairperson of the Bajrabarahi Small Farmers Agricultural Cooperative Ltd., representing more than 1,302 farmer members in the village, estimates that around 85% of agricultural land in Bajrabarahi is irrigated (personal communication, 29/10/2018).

2. Introduction

Nepal has vast water resources and approximately 67% of its cultivated land can be irrigated (MoAD, 2016). Out of the 1.7 million ha of Nepal's irrigable land, 78% has been provided with some irrigation infrastructure but it is estimated that about only two thirds of which are actually irrigated during the monsoon season (MoAD, 2016). Irrigation is vital to Nepal, especially as the country is facing climate change impacts such as rise in temperature and more erratic rainfall patterns, which is creating prolonged periods of droughts and jeopardising the agricultural production nationwide (Malla, 2009). As the supply of water for agriculture becomes more variable, water resource competition and water conflicts across the country are equally becoming increasingly visible (Biggs et al., 2013). To prepare for these challenges, many have argued that efforts need to be directed not only towards developing the country's irrigation infrastructure but also towards changing water management practices (Manandhar et al., 2011, Gentle and Maraseni, 2012 and Chhetri et al., 2012).

Irrigation infrastructure development and the irrigation management practices in Nepal have been well documented topics in the academic literature indeed (Schreier and Shah, 1996; Pradhan 2012; Joshi et al., 2017), and especially in light and in response to climate change (Malla, 2009; Chhetri and Easterling, 2010; Sujakhu et al., 2016). In their assessment of the potential impact of climate change on water resources development in the Koshi River Basin in Nepal, Bharati and al. (2014) illustratively conclude that infrastructure needs to be put in place to make it possible to store and transfer water to manage the water deficit due to any changes in rainfall or flow patterns. In contrast, based on their analysis of water availability and variability in two watersheds of the Middle Mountains of Nepal's Hindu Kush-Himalayas region, Merz and al. (2003) argue that irrigation infrastructure alone will not resolve lack of water access for agriculture and that new water governance bodies enforcing basin scale changes in practices are additionally needed.

The question of water management institutions and their ability to deal with water resource pressure and conflicts in Nepal is an equally impressive body of literature (Pradhan et al., 2000; Cifdaloz et al., 2010; Biggs et al., 2013). Upreti's (2004) analysis of natural and water resources conflict resolution practices in Nepal argues that existing formal legal procedures and informal systems are complicated, elitist, inherently biased towards those with power, and thus mainly dysfunctional. Similarly, Yates' (2011) comparative study of different water governance mechanisms in Nepal shows that water user committees generally lack the proportional representation and institutional capacity for sufficient responsiveness. Yet, Ostrom and Lam's numerous publications (e.g. Ostrom et al., 1994; 2011; Lam 1998; Lam and Ostrom, 2010) comparing agency-managed irrigation systems with farmer-managed irrigation systems have revealed how modes of collective governance in fact perform much better in terms of allocation efficiency and conflict management.

While water resource management and water conflicts in Nepal have attracted much academic attention, most of it has however come through the analytical lens of political ecology and institutionalism. This study about water conflicts between farmers of Bajrabarahi applies a novel mix-methods strategy, grounded in modelling, to identify and assess the weight that different factors play in water resource management conflicts. So far, irrigation water requirement modelling has been used in the context of Nepal only to study the possible impacts of climate change (Pant, 2013; Shrestha et al., 2013) or to study climatic and agricultural water balances (Paudel and Pandey, 2013; Adhikari and Devkota, 2016). This study therefore contributes to the water governance literature by highlighting the use of water resource modelling in disentangling water management conflicts in Nepal and elsewhere.

Figure 1 Monthly average precipitation and average minimum and maximum temperatures in Bajrabarahi (source: DoHM, 2018).

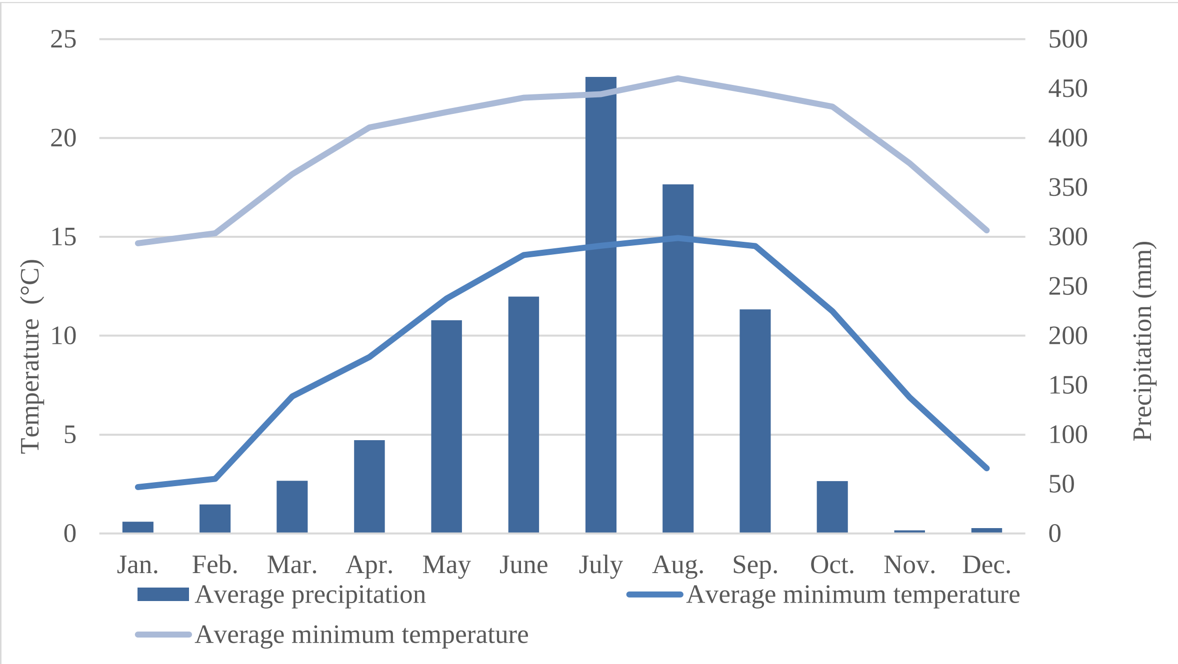


Figure 2 Satellite imagery of the Bajrabarahi Village Municipality (source Google Earth)

3. Description of the Problem

3.1. Water insecurity and rising conflicts

Though water resources appear to be abundant, water shortages have become ubiquitous in recent years and water competition in addition to conflicts are on the rise in Bajrabarahi, especially since the 2015 earthquake (Maheshwor Subedhi, personal communication, 29/10/2018). In fact, most rural communities living in the hilly regions of Nepal traditionally rely on spring water tapping for water supplies. A significant number of these springs however went dry in the aftermath of the 2015 earthquake, probably due to the fault lines that were created and which tunnelled the available water supplies directly into the ground (Figure 3). Many hilly and mountainous communities all across Nepal had to build emergency supply lines and had to resort to bottle water and water tankers until the local springs would reappear. While many of these local springs have indeed started to flow back again, the flows remain very variable and of low quality, thus leaving many rural villages in precarious positions.

Figure 3 Picture of one of the major springs now running low in the upstream areas of Bajrabarahi (source: NACCFL, 2017)

Luckily enough, the water supplies in Bajrabarahi have been generally sufficient to satisfy the drinking water demand for everyone. That being said, what is now happening in Bajrabarahi is that downstream farmers are increasingly unsatisfied with the amounts of irrigation water they are receiving. There are thus more and more incidents of sluices and gates (Figure 4) being opened when they are not according to the irrigation schedule, letting water flow to the lower fields downstream. There are even reports of farmers destroying irrigation canals in upstream areas, especially at night (Maheshwor Subedhi, personal communication, 29/10/2018).

Figure 4 Picture showing a gate system connecting irrigation canals between upstream and downstream farmers in Bajrabarahi (source: NACCFL, 2017)

The institutions traditionally responsible for managing such water conflicts, namely the local Water Users Association (WUA) and other community-based institutions such as the Bajrabarahi Small Farmers Agricultural Cooperative Ltd., have been unable to properly manage these conflicts. The irrigation schedules have been fixed and re-fixed, yet the water conflicts as illustrated by the unauthorised opening of some gates remain pervasive. In light of this the Bajrabarahi SFACL has contacted NACCFL to request help on how to understand and identify possible solutions to this difficult situation.

3.2. NACCFL

The Nepal Agricultural Cooperative Central Federation Ltd. is an umbrella organisation of 915 Small Farmers Agricultural Cooperatives Ltd. (SFACLs) such as the Bajrabarahi SFACL. The network of NACCFL stretches over 71 of the 77 districts of Nepal, representing a total of approximately 860,000 small farmers' households.

NACCFL aims at providing appropriate financial and non-financial services to all the member organizations for their institutional development and for the socio-economic development of the deprived small farmers across the country. Its objectives are grouped in three categories: (1) capacity building; (2) policy advocacy and; (3) cooperative network expansion.

In terms of capacity building, NACCFL seeks to assist member cooperatives and works directly with local communities to improve their efficiency and autonomy by providing training on different aspects:

- Cooperative and financial-cooperative management: cooperative performance, accounting keeping, loan portfolio management, financial management.
- Agriculture: cultivation practices, pest/disease management, post-harvest management, integrated pest management technology etc. .
- Institutional development aspects: proposal writing, strategic planning, business plan development, annual work and budget planning, computer training.
- Marketing aspects: cooperative marketing, market information system etc. .
- Linkage and network expansion.

As a result of many requests from its cooperative members, NACCFL started providing training and advisory services on Integrated Water Resources Management in October 2017. Some of the completed projects which NACCFL has helps its members with includes drinking water systems upgrading, springshed conservation and management, diffusion of irrigation efficiency technologies (e.g. drip, sprinkler, underground, etc.). In addition, NACCFL now offers a range of specialised training in water management such as irrigation management for fruit and vegetable production and water quality testing. In delivering water related training and technologies, NACCFL is leveraging collaborations across the various levels of government, NGOs and the private business industry.

4. Decisions and Actions Taken

4.1. Decisions: research approach

Relying on a team of agricultural experts and irrigation specialists, NACCFL deployed a research team aiming to work directly with the local farmers of the Bajrabarahi SFACL. Trying to make a better sense of this water conflict and hopefully pave the way toward resolving it, the team developed four specific research objectives:

1. Determine the period(s) of the year when water shortages are most acute;
2. Reveal which crops are affected and for how long;
3. Identify and assess the weight of the major factors behind these water shortages;
4. Highlight the farmers' belief on the reasons explaining these water shortages.

To respond to these key objectives, the research team designed and applied a mix method strategy composed of questionnaire interviews and crop water requirement modelling using CROPWAT 8.0.

Questionnaire survey was used to collect information on agricultural and water management practices. The questionnaire contained twelve questions which were translated from English to Nepali and conducted in Nepali by a native speaker. As suggested by McLafferty (2016), open-ended questions always preceded close-ended ones in order to maximize flexibility and depth in the interviewees' responses. The questionnaire was conducted with forty-one respondents across the farmland of the Bajrabarahi community, interviewing farmers as they were encountered (Figure 5). Farmers were classified as either "upstream" or "downstream" depending on the ratio between the number of farmers they believed to be higher and lower than them *and* who depended on the same water resources for irrigation. This self-assessment was crossed-checked using maps to identify the location of each farmer. Out of the 41 farmers, 26 of them were identified as upstream farmers and the remaining 15 were classified as downstream.

Figure 5 Questionnaire interviews conducted with small farmers in Bajrabarahi

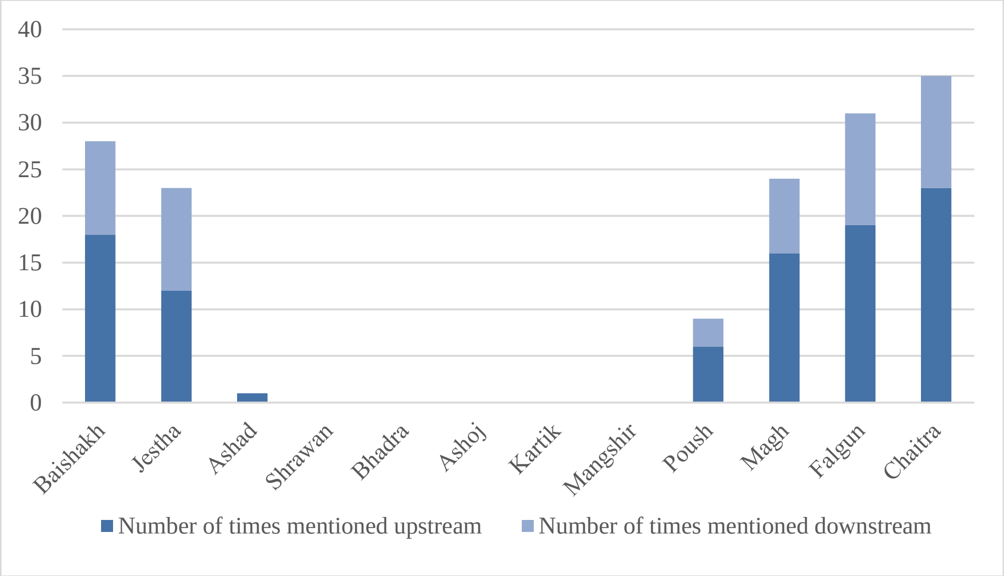
CROPWAT 8.0 was used to estimate the irrigation water requirements for the three main irrigated crops cultivated in Bajrabarahi. This software computes irrigation water requirements based on agricultural and climatic data and relies on the Penman-Monteith equation for evapotranspiration calculations. The climate data inputted into CROPWAT was obtained from records of the closest meteorological station to Bajrabarahi, the Daman Station (Lat. 27.36/Log. 85.05). Daily records from January 2000 to April 2016, including for maximum and minimum temperatures, precipitation, hours of sunlight, wind and relative humidity were provided by Department of Hydrology and Meteorology, Nepal Ministry of Population and Environment. Climate data was triangulated with the neighbouring stations of Hetauda and Khumaltar. Records for these two stations were obtained though CLIMWAT 2.0, a climatic database developed by the FAO to be used in combination with CROPWAT.

4.2. Determine the period(s) of the year when water shortages are most acute

The nature of the hydrological cycle entails that water resource competition between farmers in Bajrabarahi (as elsewhere in Nepal) varies inter- and intra-seasonally. Water shortages, and by extension water resource competition, are consequently bound to temporal variations as well. Understanding the water for irrigation conflict therefore had to start with identifying the period(s) of the year when water shortages are most acute. For that purpose, the research team collected information on the farmers' perception on when and for how long are water for irrigation deficiencies generally experienced.

When asked to name the different periods of the year where water shortages are most acute in an open-ended question, both upstream and downstream farmers predominantly mentioned in similar proportions the month of Chaitra (mid-March to mid-April) (Figure 3). Second and third are the months of Falgun (mid-February to mid-March) and Baishakh (mid-April to mid-May), respectively. However, when asked to rank the most intense periods of the year for water shortages, both upstream and downstream farmers identified the month of Falgun, six times each for a total of twelve times. Closely follows Chaitra with five and five mentions, totalising ten times. Finally, Magh (mid-January to mid-February) and Jestha (mid-May to mid-June) were individually mentioned as the most intense month of water shortage seven and six times in total. In summary, farmers believe to be water short from approximately mid-January to mid-June, with March, April and May being identified as the most intense period of water stress.

Figure 6 Farmers' perceptions on water shortages by month



4.3. Reveal which crops are affected by water shortages and for how long

In trying to understand and better respond to irrigation water conflicts, it is important to additionally identify which crops are affected and for how long. For that purpose, the research team collected information on the agricultural calendar in Bajrabarahi and set it against the farmers' perceptions on water shortages that were highlighted in the previous sub-section.

The farmers of Bajrabarahi cultivate both irrigated and rain fed crops (Table 1). The three main irrigated crops grown in Bajrabarahi are rice, potatoes and crucifers. Irrigated crops grow almost throughout the entire year (land is left barren from mid-November to mid-January). The rice growing period stretches a little before and after months of the summer monsoon, approximately from mid-Jestha to mid-Kartik (late May/early June to late October). Potatoes and crucifers, which are the two other major irrigated crops types cultivated by Bajrabarahi's farmers are grown during the winter and springtime. The growing season for potatoes goes from mid-Magh (the first week of February) to the end of Jestha (early to mid-June). Crucifers, primarily cauliflowers intercropped with cabbages, are planted around the middle of Poush (early/mid-January) and harvested slightly after potatoes in mid-Āshādh (mid/late June).

Table 1 Agricultural calendar of major crops in Bajrabarahi

	Gregorian calendar	*Apr.-May*	*May-June*	*June-July*	*July-Aug.*	*Aug.-Sep.*	*Sep.-Oct.*	*Oct.-Nov.*	*Nov.-Dec.*	*Dec-Jan.*	*Jan.-Feb.*	*Feb.-Mar.*	*Mar.-Apr.*
	Nepali cal.	*Bai.*	*Jes.*	*Ash.*	*Shr.*	*Bha.*	*Ash.*	*Kar.*	*Man.*	*Pou.*	*Mag.*	*Fal.*	*Cha.*
Irr.	*Rice*		Plant				Harvest						
	Potato	Harvest									Plant		
	Crucifers		Harvest							Plant			
Rain fed	*Maize*				Harvest								Plant
	Chili		Plant					Harvest					
	Peas	Harvest								Plant			
	Mustard						Plant		Harvest				

Putting together the results from the perceptions of water shortages with information on the agricultural calendar, we can easily discern that the water shortages are impacting more potatoes and crucifers than rice production (see red gradation in Table 1). The three months that have been identified as the most water scarce correspond directly to the growing period for these two specific crops. That said, we can see that the beginning of the rice planting season also corresponds to a period of perceived water shortage, although to a latter extent.

4.3. Identify and assess the weight of the major factors behind these water shortages

Having identified the seasonality of the water shortages and the types of crops that are most impacted, the research team's next aim was to identify and assess the weight of the major factors behind these water shortages. We tried to determine the impact of agricultural and climatic factors using CROPWAT 8.0, a crop water requirement modelling software. Then, we aimed to see the potential impact which farmers have on the available water resources. We did so by comparing the optimal crop water requirements, as per calculated using the software, with the actual water use of farmers, which was collected through survey questionnaire.

- Agricultural and climatic factors

The months which farmers identified as periods of most severe water shortage (basically from Poush to Chaitra or from mid-January to mid-April) are months: (1) when the irrigation water requirements for potatoes and crucifers are highest and; (2) when precipitation is well below the 100mm bar. Irrigation water requirements begin to rise, especially for cauliflower and cabbage, from mid-January to February onwards. They reach their respective maximum in the months of March and April when effective rainfall is around 20 mm monthly average (DoHM, 2018). Ninety-one percent of the total crop water requirements for potato (86.4 mm or 86 litres/m^2) are in fact concentrated in April and March (Table 2) and 53% of the total irrigation water requirements for crucifers are in these two months as well (Table 3). The aforementioned farmers' perceptions therefore clearly echo the rising pattern in the irrigation water requirements for the period culminating to Falgun and Chaitra (mid-February to mid-March and mid-March to mid-April). The conclusion is that there is a major mismatch between crops water requirements and precipitation patterns for the winter and spring period.

Table 2 Crop water requirements for potato

Month	*Decade*	*Stage*	*Kc coeff.*	*Etc mm/day*	*Etc mm/dec*	*Eff rain mm/dec*	*Irr. Req. mm/dec*
Jan	*3*	Init	0.5	0.96	2.9	1.5	2.9
Feb	*1*	Init	0.5	1.03	10.3	7.4	2.9
Feb	*2*	Init	0.5	1.1	11	9.2	1.8
Feb	*3*	Deve	0.55	1.36	10.9	11.5	0
Mar	*1*	Deve	0.74	1.99	19.9	13.6	6.3
Mar	*2*	Deve	0.95	2.79	27.9	15.7	12.2
Mar	*3*	Mid	1.11	3.55	39	19.4	19.6
Apr	*1*	Mid	1.13	3.85	38.5	22.3	16.2
Apr	*2*	Mid	1.13	4.13	41.3	25.4	15.9
Apr	*3*	Mid	1.13	4.12	41.2	32.6	8.6
May	*1*	Late	1.12	4.1	41	42	0
May	*2*	Late	1.02	3.73	37.3	49.6	0
May	*3*	Late	0.88	3.05	33.5	49.5	0
Jun	*1*	Late	0.75	2.48	17.4	33.6	0
					372.2	**333.4**	**86.4**

Table 3 Crop water requirements for crucifers

Month	*Decade*	*Stage*	*Kc coeff.*	*Etc mm/day*	*Etc mm/dec*	*Eff rain mm/dec*	*Irr. Req. mm/dec*
Jan	*2*	Init	0.7	1.25	8.8	2.4	7
Jan	*3*	Init	0.7	1.35	14.8	5.4	9.4
Feb	*1*	Init	0.7	1.45	14.5	7.4	7
Feb	*2*	Init	0.7	1.54	15.4	9.2	6.2
Feb	*3*	Deve	0.71	1.75	14	11.5	2.5
Mar	*1*	Deve	0.76	2.05	20.5	13.6	6.9
Mar	*2*	Deve	0.81	2.39	23.9	15.7	8.2
Mar	*3*	Deve	0.87	2.76	30.4	19.4	11
Apr	*1*	Deve	0.92	3.16	31.6	22.3	9.3
Apr	*2*	Deve	0.98	3.58	35.8	25.4	10.4
Apr	*3*	Mid	1.01	3.71	37.1	32.6	4.5
May	*1*	Mid	1.02	3.71	37.1	42	0
May	*2*	Mid	1.02	3.71	37.1	49.6	0
May	*3*	Mid	1.02	3.53	38.9	49.5	0
Jun	*1*	Mid	1.02	3.36	33.6	48	0
Jun	*2*	Late	0.99	3.1	31	48.5	0
Jun	*3*	Late	0.93	2.79	19.6	35.9	0
					444	**438.6**	**82.5**

The perceptions of water shortages noted at beginning and just before the monsoon season mirror the large water requirements that are needed during in the early stages of rice cultivation. Total irrigation requirements for rice are 227.4 mm (227.4 litres/m^2) and three quarters of that water (207 mm or 207 litres/m^2) are needed at the nursing and initial development stages of the plant (Table 4). Most farmers start to store water and to irrigate their land as early as the beginning of May in order to secure sufficient water resources for this period, hence explaining why farmers perceive there to be water scarcities from the mid/end of Baishakh to the end of Jestha. From the beginning of July until late September, precipitation is sufficient to meet the crop water requirements so no additional irrigation is needed. Perceptions on water shortages too fall to virtually zero for this entire five months' period. Irrigation water, although in much smaller quantities (20.4 litres/m^2), are once again needed when the rice reaches its late development stages in October. However, this increase in irrigation water demand was not reflected in the farmers' perceptions on water shortages. One of the possible reasons for that are the great amounts of water are sporadically released as farmers begin to selectively drain their rice paddies in preparation for harvest during these weeks.

Table 4 Crop water requirements for rice

Month	*Decade*	*Stage*	*Kc coeff.*	*Etc mm/day*	*Etc mm/dec*	*Eff rain mm/dec*	*Irr. Req. mm/dec*
May	*3*	Nurs	1.2	0.42	2.9	31.5	0
Jun	*1*	Nurs/ LPr	1.11	2.58	25.8	48	49.1
Jun	*2*	Nurs/ LPr	1.06	3.33	33.3	48.5	98
Jun	*3*	Init	1.09	3.29	32.9	51.3	59.9
Jul	*1*	Init	1.1	3.19	31.9	55.5	0
Jul	*2*	Deve	1.1	3.07	30.7	58.7	0
Jul	*3*	Deve	1.11	3.11	34.2	56.9	0
Aug	*1*	Deve	1.12	3.14	31.4	54.8	0
Aug	*2*	Mid	1.13	3.16	31.6	53.6	0
Aug	*3*	Mid	1.13	3.18	35	51.8	0
Sep	*1*	Mid	1.13	3.21	32.1	52.4	0
Sep	*2*	Mid	1.13	3.23	32.3	51.9	0
Sep	*3*	Late	1.11	3.11	31.1	40	0
Oct	*1*	Late	1.07	2.93	29.3	25.2	4.1
Oct	*2*	Late	1.02	2.75	27.5	13.7	13.8
Oct	*3*	Late	1	2.52	2.5	0.9	2.5
					444.5	**694.7**	**227.4**

- Human factors

Now that the water shortages are established to be the result of a combination between low effective rainfall in periods of high crop water demand, the next question is what is the human impact on the available water supplies for irrigation. A comparison between CROPWAT estimates for crop irrigation requirements and actual water use of farmers in Bajrabarahi reveals that mismanagement, especially by the upstream farmers, contributes to these seasonal water shortages. In fact, results from agricultural survey indicate that farmers tend to use much more water than CROPWAT's irrigation requirement estimations for each of the three major irrigated crop grown in the area (Table 5). Results also show that mismanagement is concentrated in the uplands and that downstream farmers actually tend to use much less than CROPWAT irrigation requirements.

Table 5 CROPWAT irrigation requirements versus actual irrigation water use

	*Rice (l/m^2)**	*Potato (l/m^2)***	*Crucifers (l/m^2)***
CROPWAT Irr. Req.	50	86.4	82.5
Total avg. water use	53.97 (n = 29)	119.3 (n = 29)	92.74 (n = 23)
Avg. water use up.	62.37 (n = 20)	126 (n = 20)	106.5 (n = 12)
Avg. water use down.	36.67 (n = 9)	104.4 (n = 9)	77.72 (n = 11)

*Average continuous flooding levels
**Total crop water use

Although the flooding levels will vary with the development stages of the plant, the FAO model recommends using 5 cm or the equivalent of 50 l/m^2 as threshold for continuous flood level for rice (FAO, 2006). The average continuous flooding levels for farmers that were interviewed was 53.97 l/m^2, which is almost 4 litres per square metre more than the software's standard optimal. The difference between actual irrigation water use and CROPWAT irrigation requirements estimations are even larger for the two other irrigated crops. Compared with CROPWAT estimates, the total average water use was 38% (or 32.9 l/m^2) higher for potatoes and 12% (or 10.24 l/m^2) higher for crucifers.

What appears from disaggregating the data, however, is that upstream communities use 70% more water for rice, 21% more for potatoes, and 37% more for crucifers compared to their downstream counterparts. Downstream farmers not only use much less than their upstream counterparts but they also fall well below software irrigation requirements, at least for rice and cauliflower. The average actual water use for rice production for downstream farmers is 36,67 l/m^2, that is, 25.7 l/m^2 and 13.33 l/m^2 lower than upstream average use and the CROPWAT calculations, respectively. The average total demand for irrigation water in terms of cauliflower and cabbage production was 77.72 l/m^2 for downstream farmers, again much lower water use than for the uplands (106.5 l/m^2) and than what the suggested optimal (82.5 l/m^2).

4.4. Highlight the farmers' beliefs on why these water shortages occur

What we managed so far was to identify the seasonality of the water shortages, which crops are most impacted, and the factors behind these shortages. The research team has additionally attempted to identify the farmers' belief on the reasons explaining these water shortages occur. This information is useful in terms of understanding how farmers perceive what is their relationship with these water shortages, and by extension, their awareness of their negative impact on the available supplies of water for irrigation.

Over-irrigation by farmers (predominantly those upstream), leads to regular water shortages as seen in Bajrabarahi. Nevertheless, and perhaps contradictorily, mismanagement is not recorded as one of the primary reasons behind shortages based on the local farmers' opinion. In fact, when asked to state up to three causes for punctual lacks of irrigation water, farmers' have predominantly mentioned earthquakes, twenty-one times, while deforestation and increase in population came in second, being identified overall twenty times each. Climate change and the construction of roads (such as the Chandragiri-Chitlang link) were also perceived as factors, although minor being respectively mentioned seven and three times. Overall, human mismanagement of water resources and over-irrigation were mentioned only three times.

To refine these answers, farmers were then asked to rank five causes identified in the questionnaire, namely: (a) climate change; (b) rain failure; (c) water mismanagement by other farmers; (d) earthquakes and landslides and; (e) deforestation. Earthquakes and landslides were identified as the principal contribution to regular water shortages, at a total average of 1.59 (Table 6). Then followed in order: climate change, deforestation, rain failure, and mismanagement. The average ranking for the five factors remained unexpectedly the same across upstream and downstream farmers with no significant differences among the two groups. Interestingly enough, water mismanagement by other farmers was mentioned only once as the number one factor, and that by an upstream farmer, clearly coming in last position with a total average of 4.71. These results demonstrate the urgent need in raise awareness amongst farmers on irrigation mismanagement.

Table 6 Average of farmers' rankings of factors behind water shortages (scale from 1 to 5)

	Earthquake	*Climate change*	*Deforest.*	*Rain failure*	*Mismanagement*
Average up. (n=25)	1.48	2.48	2.76	3.64	4.64
Average down. (n=16)	1.75	2.50	2.69	3.25	4.81
Average total (n=41)	1.59	2.49	2.73	3.49	4.71

5. Outcome/Results

This case study has elucidated a number of elements regarding the water for irrigation conflicts in Bajrabarahi. Each of these research outcomes are essential to devising an adequate response strategy for managing these conflicts.

1. **Seasonality of water shortages**: The team showed that water resource shortages in Bajrabarahi are present for almost half of the year. Based on the farmers' perception, we found out that water shortages occur from Poush (mid-December to mid-January) to Ashad (mid-June to mid-July). Out of these months, the period from Falgun to Baihakh, basically from mid-February to mid-May, was the time of most severe water shortage.

2. **Crops affected by water shortages:** The small farmers of Bajrabarahi grow three types of irrigated crops, potatoes, crucifers, and rice. The study has demonstrated that potatoes and crucifers are most impacted by water shortages. Rice is also impacted by water shortages but

only during its nursery and early development stages. Potatoes and crucifers are, on the other hand, impacted by water shortages all thought-out their growing season.

3. **Factors behind water shortages:** This study has found that water shortages are predominantly explained though a combination of agricultural and climatic factors. Essentially what we found is that the crop water requirement spike at the same time when the average precipitation is still well below a 100mm mark, thus causing a condition of water deprivation. That being said, what was also revealed it how mismanagement, especially by upstream farmers, is exacerbating the natural water scarcity.

4. **Farmers' beliefs on why water shortages occur:** NACCFL's team discovered that the farmers do not think their water management practices have much weight in explaining why water shortages occur. In fact, the majority of small farmers in Bajrabarahi believe that factors such as earthquakes and climate change are the lead responsible causes and that human mismanagement has very little influence on water scarcity in the area.

Beneficiaries

This study was conducted by NACCFL on behalf of the local SFACL which represents 1,302 farmers' household in Bajrabarahi. Out of the 1,302 farmer members 57% are women and 32% are below 35 years old. The findings of this study and its recommendations has been presented to the board of the Bajrabarahi Small Farmers Agricultural Cooperative and also to the local Water User Association, which are the two leading bodies responsible for implementing measures and actions in the community. Our hopes are thus that this study will inform more sustainable and more equitable irrigation management practices not only for the members of the cooperative but for all the 1,630 farmers' households of Bajrabarahi (total population of 7,675).

6. Lessons Learned

There are several important lessons to be drawn from this study on water for irrigation conflicts between small farmers in the Bajrabarahi Village Municipality.

- Modelling can be used as a tool for farmers to better understand the relationship between the natural water supply and crop water demand, ultimately giving them information on how to adapt agricultural and water management practices.
- Computer software on irrigation crop requirements can help farmers determine the optimal irrigation water use. Water resource modelling can thus be used as a benchmark to determine who is over irrigating and who is under irrigating and therefore also act as an arbitrating instrument in water management conflict situations.
- Water management institutions such as Water User Associations are essential bodies for negotiating water resource conflicts amongst users. Partnerships between these bodies and research organisations can help foster a wider and more informed dialogue on good water management practices.

- Raising awareness and engaging as many stakeholders as possible is key to achieving implementing an integrated water management strategy. Guaranteeing the equitable and environmentally sustainable use of water needs to be understood as a shared common responsibility for all.

Recommendations

- Water use restrictions should be put in place during the periods of severe water shortages, especially during the months of Falgun to Baihakh (mid-Febuary to mid-May).
- Potato and crucifers have relatively high water requirements. Switching to crops with lower water coefficients (e.g. grains or even lettuce or spinach) should be considered.
- Hydrological and climatic information should be diffused to farmers so that they can make more informed decisions on their cropping calendar. Shifting the planting season by even one or two weeks can indeed help match the seasonality of crop water requirements with precipitation patterns.
- The most common irrigation method in Bajrabarahi is flood irrigation. Other methods of irrigation methods such as drip or sprinkler systems can help distribute water more effectively thus diminish water losses though runoff and evaporation.
- If flood irrigation remains the dominant form of irrigation, checks should be made so that farmers, especially those in the upstream sections, do not surpass a certain flood level.
- A monitoring and enforcement system for the sluice and irrigation schedule should be maintained by the relevant water bodies.
- Efforts should be made to reinforce the local bodies responsible for dealing with water management issues, e.g. the Water User Associations and the Small Farmers Agricultural Cooperatives.
- Water resource modelling should be included as part of the institutional mechanisms for dealing with water resource management conflicts among users.
- Farmers need to be sensitize about their potential impact on the available water supplies. A vast awareness campaign can help promote knowledge of good water management practices and spark a genuine interest towards guarantying a more sustainable and equitable use of water.

7. Conclusion

This study conducted by NACCFL on behalf of the Bajrabarahi SFACL has shed light on the seasonality of water demand competition and showcased the main factors behind the punctual water shortages for agriculture occurring in the Bajrabarahi. Based on the farmers' perceptions and on CROPWAT estimates on irrigation water irrigation, it has been shown that water demand is highest during the beginning of the monsoon season and in the middle of the spring growing period. The surge in water resource competition around early/mid-May to mid-June was shown to closely correspond to the period when crop water requirements for rice are on the rise while effective rainfall is still relatively low. The water shortages noticed from mid/late January to mid-April was shown to match to peaks in water irrigation requirements for potatoes and for crucifers.

This case study has argued that the water shortages, and by extension water conflicts in Bajrabarahi, can be primarily explained through a combination of agricultural and climatic factors.

The research team has also rightfully demonstrated how human mismanagement has contributed to aggravating the levels of water stress in this agricultural community. By comparing CROPWAT irrigation requirements and actual irrigation water use of farmers that the average farmer tends to over irrigate by 8% for rice, 12% for crucifers and 38% for potatoes. Disaggregating the data between upstream and downstream communities however revealed that most of this mismanagement was actually concentrated in the upland communities and that downstream farmers in fact mostly fell short of their water requirements. Additionally, it was also found that most farmers of Bajrabarahi believe that human mismanagement of water resources has although little to do with water shortages.

This study has made a clear case of the extent to which water resource modelling, especially used in combination with a range of qualitative inputs, can be beneficial to disentangling water resource conflicts and identifying ways of moving forward with better understanding and education of more sustainable and equitable water resource management. NACCFL will continue working with a range of partners and Small Farmers Agricultural Cooperative to encourage the use of water resource models to promote better water management practices in Nepal and abroad.

8. References

Adhikari, T. R., & Devkota, L. P. (2016). Climatic Water Balance of Annapurna, Langtang and Khumbu regions of Nepal Himalaya. *Journal of Hydrology and Meteorology*, *8*(1), 47-57.

Bharati, L., Gurung, P., Jayakody, P., Smakhtin, V., & Bhattarai, U. (2014). The projected impact of climate change on water availability and development in the Koshi Basin, Nepal. *Mountain Research and Development*, *34*(2), 118-130.

Biggs, E. M., Duncan, J. M., Atkinson, P. M., & Dash, J. (2013). Plenty of water, not enough strategy: How inadequate accessibility, poor governance and a volatile government can tip the balance against ensuring water security: The case of Nepal. *Environmental science & policy*, *33*, 388-394.

Central Bureau of Statistics (CBS) (2014). *National Population and Housing Census 2011 (Village Development Committee/Municipality) Makawanpur*. Government of Nepal, National Planning Commission Secretariat Central Bureau.

Chhetri, N. B., & Easterling, W. E. (2010). Adapting to climate change: Retrospective analysis of climate technology interaction in the rice-based farming system of Nepal. *Annals of the Association of American Geographers*, *100*(5), 1156-1176.

Chhetri, N., Chaudhary, P., Tiwari, P. R., & Yadaw, R. B. (2012). Institutional and technological innovation: Understanding agricultural adaptation to climate change in Nepal. *Applied Geography*, *33*, 142-150.

Cifdaloz, O., Regmi, A., Anderies, J. M., & Rodriguez, A. A. (2010). Robustness, vulnerability, and adaptive capacity in small-scale social-ecological systems: The Pumpa Irrigation System in Nepal. *Ecology and Society*, *15*(3).

Department of Hydrology and Meteorology—DoHM (2018) *Meteorological Data: Daman Station (January 2000 to April 2016).* Kathmandu: Nepal Ministry of Population and Environment.

Food and Agricultural Organisation—FAO (2006) CROPWAT 8.0. [Computer software]. Rome: FAO.

Gentle, P., & Maraseni, T. N. (2012). Climate change, poverty and livelihoods: adaptation practices by rural mountain communities in Nepal. *Environmental science & policy*, *21*, 24-34.

Joshi, J., Ali, M., & Berrens, R. P. (2017). Valuing farm access to irrigation in Nepal: A hedonic pricing model. *Agricultural water management*, *181*, 35-46.

Lam, W. F. (1998). *Governing irrigation systems in Nepal: institutions, infrastructure, and collective action*. Institute for Contemporary Studies.

Lam, W. F., & Ostrom, E. (2010). Analyzing the dynamic complexity of development interventions: lessons from an irrigation experiment in Nepal. *Policy Sciences*, *43*(1), 1-25.

Malla, G. (2009). Climate change and its impact on Nepalese agriculture. *Journal of agriculture and environment*, *9*, 62-71.

Manandhar, S., Vogt, D. S., Perret, S. R., & Kazama, F. (2011). Adapting cropping systems to climate change in Nepal: a cross-regional study of farmers' perception and practices. *Regional Environmental Change*, *11*(2), 335-348.

McLafferty, S.L. (2016). Conducting questionnaire surveys. In: Clifford, N., Cope, M., Gillespie, T. and French, S. eds., 2016. *Key methods in geography*, Thousand Oaks: SAGE Publications Sage. 87-100.

Merz, J., Nakarmi, G., Shrestha, S. K., Dahal, B. M., Dangol, P. M., Dhakal, M. P., ... & Weingartner, R. (2003). Water: A scarce resource in rural watersheds of Nepal's Middle Mountains. *Mountain Research and Development*, *23*(1), 41-49.

Ministry of Agricultural Development—MoAd (2016). *Statistical Information on Nepalese Agriculture 2072/73 (2015/16)*. Government of Nepal, Monitoring, Evaluation and Statistics Division Agricultural Statistics Section.

Ostrom, E., Lam, W. F., & Lee, M. (1994). The performance of self-governing irrigation systems in Nepal. *Human Systems Management*, *13*(3), 197-207.

Ostrom, E., Lam, W. F., & Pradhan, P. (2011). *Improving irrigation in Asia: Sustainable performance of an innovative intervention in Nepal*. Edward Elgar Publishing.

Pandey, V. P., Babel, M. S., & Kazama, F. (2009). Analysis of a Nepalese water resources system: stress, adaptive capacity and vulnerability. *Water Science and Technology: Water Supply*, *9*(2), 213-222.

Pant, K. P. (2013). Economics of climate change for smallholder farmers in Nepal: a review. *Journal of Agriculture and Environment*, *12*, 113-126.

Paudel, H. D., & Pandey, A. (2013). Comparative study of ETo estimation methods for the water balance estimation–A case study of Sikta irrigation project, Nepal. *Journal of Indian Water Resources Society*, *33*(4), 42-50.

Pradhan, P. (2012). Revitalizing irrigation systems for food security: Vision and approaches in Nepal irrigation systems. *Hydro Nepal: Journal of Water, Energy and Environment*, *11*(1), 44-49.

Pradhan, R., Pradhan, U., Bruns, B. R., & Meinzen-Dick, R. S. (2000). Negotiating access and rights: A case study of disputes over rights to an irrigation water source in Nepal. *Negotiating water rights*.

Schreier, H., & Shah, P. B. (1996). Water dynamics and population pressure in the Nepalese Himalayas. *GeoJournal*, *40*(1-2), 45-51.

Shrestha, S., Gyawali, B., & Bhattarai, U. (2013). Impacts of climate change on irrigation water requirements for rice–wheat cultivation in Bagmati River Basin, Nepal. *Journal of Water and Climate Change*, *4*(4), 422-439.

Sujakhu, N.M., Ranjitkar, S., Niraula, R.R., Pokharel, B.K., Schmidt-Vogt, D. and Xu, J., 2016. Farmers' Perceptions of and Adaptations to Changing Climate in the Melamchi Valley of Nepal. *Mountain Research and Development*, *36*(1), pp.15-30.

Upreti, B. R. (2004). Resource conflicts and conflict resolution in Nepal. *Mountain research and development*, *24*(1), 60-66.

Yates, J. (2011). Limits to adapting to water variability in rural Nepal: Gaps in community-based governance. *Waterlines*, *30*(2), 106-121.

9. Contact details

10. Supporting References