Framework for effectiveness and resilience of small- and medium-scale irrigation systems in Nepal[1]

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Preface

This report has been able to capture and assess information with a comprehensive analysis of the impact of climate change in small- and medium-scale irrigation systems in Nepal. Special efforts have also been made over a considerable amount of time to establish a framework for effectiveness and resilience of the irrigation systems developed by Nepali farmers. This is a significant accomplishment, because it not only provides the concerned stakeholders with ample information for the development of climate-resilient irrigation infrastructure, but also provides a guidance framework for carrying out sensitive tests to analyse and mitigate the risk of catastrophic damage at system, institution and agent levels.

I would like to thank the whole team at Mott MacDonald, United Kingdom, for producing such a comprehensive document covering a number of case studies, including climatic and non-climatic factors that impact on agricultural production.

I am confident that this report will be helpful to different stakeholders, including policy-makers, farmers organisations, academics and engineers from the Department of Irrigation, to appraise the role of climate change in the overall future of irrigation development in Nepal.

Finally, I would like to encourage all the irrigation system planners to widely apply the information contained in this report in formulating a strategy to address the resilience issues at the level of individual farmers, communities and irrigation systems, at every stage, in order to take on climate-resilient irrigation development.

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Executive summary

Introduction

Out of 2.7 million hectares of agricultural land in Nepal, only 1.3 Mha have irrigation facilities. The majority of irrigation systems are small and medium scale. Agriculture is a mainstay of the economy of Nepal, providing about 33% of the gross domestic product (GDP) and supporting the livelihoods of most of the population. Livelihoods based on agriculture are vulnerable due to the monsoon climate and the topography.

A recent study funded by the Climate and Development Knowledge Network (CDKN) revealed that about 0.8% of agricultural GDP is being lost annually due to climate change and extreme events. There is a need to both improve agricultural productivity and make it more resilient to climate uncertainty and change in general. Recent increases in floods and droughts have raised concerns that the climate is changing rapidly and that existing arrangements for irrigation design and management may need to be reconsidered.

In light of these concerns, a project was undertaken for CDKN in 2015-2016 to develop a framework for the effectiveness and resilience of small- and medium-scale irrigation. It was delivered by Mott MacDonald working with the Farmer Managed Irrigation System Promotion Trust (FMIST), the Centre for Engineering Research and Development (CERD), and ADAPT-Nepal, in conjunction with the Department of Irrigation, Government of Nepal, with funding from the United Kingdom (UK) Department for International Development (DFID). The aims of this project were to:

- help the government, especially the Department of Irrigation, and other stakeholders understand the impacts of climate change
- develop a framework for improving the resilience and effectiveness of (both existing and potential) small- and medium-scale irrigation systems
- improve the approach and methodology for planning, delivery and management of efficient, effective, equitable and climate-resilient irrigation
- assess processes, institutions and policy
- prepare a framework to increase the climate resilience and effectiveness of small- and medium-scale irrigation systems, ensuring that it is understood by relevant stakeholders.

This paper synthesises the findings and recommendations from the project and is intended for policy-makers, planners and implementers working in Nepal's irrigation sector under uncertain conditions induced by climate change. It provides guidance to irrigation sector project designers and policy-makers on assessing climate risks at the project and system levels, and on mitigating the risks using the resilient approach.

Methodology

The study adopted a two-pronged approach involving both top-down and bottom-up analysis. The top-down approach focused on understanding Nepal's specific climate vulnerabilities and the overall performance of the irrigation sector in the country, including the challenges and opportunities for sustained agricultural growth brought on by climate change phenomena in Nepal. The broader picture of the climate factors affecting the sector was constructed through analysis of existing climate data and literature, and projections of climate change for alternative emission scenarios and timescales from CMIP5 (Fifth Coupled Model Inter-comparison Project) through desk research. To assess current and projected impacts of climate change on small- and medium-scale irrigation systems, the project reviewed climate models, analysed irrigation status and inventory of Nepal, and reviewed relevant policies and programmes shaping the sector. The top-down approach helped develop broad knowledge on irrigation performance from the perspective of climate change.

Because of the diverse biophysical and socioecological systems in Nepal, the information derived from the top-down analysis needed to be verified through location-specific studies. So, the study undertook a bottom-up approach to understand climate vulnerability and performance of irrigation systems at field level. For this, reconnaissance field visits were made to 17 irrigation systems, and two river basins were selected for detailed case studies.

The site selection criteria (surface irrigation system, comparatively drier area, past data availability, and small- or medium-scale systems) were adopted on the basis of lessons drawn from the reconnaissance study. Surface irrigation systems were made the candidate for detailed study. Singheghat irrigation system of the Banaganga basin in Kapilvastu District and Julphe irrigation system of the Girwari basin in Nawalparasi District were selected as the case studies. The study also examined the basins as a whole and other irrigation systems within them.

Both qualitative and quantitative data were collected. The qualitative data methods included walk-throughs of the systems and basins; observations; and interviews with farmers on water management and their perceptions of climate change. Quantitative data included information from the meteorological stations of Bhairawa Airport, Patharkot (Kapibastu) and Belwa (Nawalparashi). Local stations at the system level were established to record rainfall and temperature, and water flow in the canals. Participatory approaches were adopted in the form of participatory rural appraisal (PRA) of the systems, focus group discussions(FGDs) and household surveys conducted in collaboration with the farmers and water user associations of the systems. District irrigation officials helped with field data collection. Detailed studies on the selected basins and irrigation systems were conducted over a period of six months, from April to September 2016, covering the spring and monsoon cropping seasons.

Overall findings

Climate change is predicted to affect seasonal water availability, which could have serious impacts on irrigation systems, and consequently on Nepal's overall economy. Temperature and precipitation are two key climatic variables most influenced by climate change.

The case studies of the two river basins revealed that their irrigation systems are severely affected by climatic and non-climatic factors.

The impacts of climate change include:

- reduced run-off in rivers, due to changing rainfall patterns in the catchment
- increased flood flows, due to more intense rainfall
- increased demand for water, due to higher temperatures and more erratic rainfall
- changes in crop suitability.

The impacts of non-climatic factors include:

- land use change
- increased water consumption upstream
- resource mining (sand, gravel) in the rivers
- migration from rural areas with adverse consequences for irrigated agricultural practices.

The study showed that the impacts of non-climatic factors are more important in the short term for most small- and medium-scale irrigation systems, with the possible exception of the impact of increased rainfall intensity on flood risk. In the longer term, climate impacts will become much greater than they are today.

The project found climate change induced threats of two types on irrigation:

- flooding/flash floods
- changes in seasonal water availability.

For small- and medium-scale irrigation systems located in dry areas, the changes in seasonal water availability are likely to be more important, whereas flood damage is likely to be a greater risk for other schemes.

- It was determined that groundwater irrigation is relatively more resilient to climate change than surface irrigation.
- For longer-term water availability and water demand, it is vital to consider the entire basin rather than looking solely at individual systems.
- To make the irrigation systems climate resilient, there is a strong need to enhance technical design, improve water use efficiency, adapt agricultural practices, improve water use governance and build robust institutions.

These may endow irrigation systems with strong absorptive capacity, helping them to persist; adaptive capacity, leading to incremental adjustments and adaptation; and transformative capacity, leading to transformational responses in the face of expected and unexpected changes.

Although the concept of resilience in irrigation systems is evolving, the project has proposed a framework to make irrigation systems resilient. The framework covers the overall vulnerability of the irrigation systems and the key features of resilience include:

- systems (infrastructure, river basins)
- institutions (rules, management)
- agents (individuals, organisations).

All three elements of the framework should be addressed together. The responses should be designed based on a good understanding of the vulnerability context (including climate extremes and trends, as well as other facets of vulnerability).

Options to strengthen climate-resilient development in the irrigation sector

- The climate is changing and its impact on agriculture will only get worse. Water is already scarce. River basins are stressed and need to be better managed to ensure that, water is used in the best possible way.
- The smaller the basin the more sensitive it is to change, and most irrigation in Nepal is dependent on small catchments.
- Adaptive management is essential – irrigation can be developed gradually as the situation changes.
- Any changes in watersheds are carefully monitored and introduced incrementally as they are needed. Sensitivity tests can be conducted to analyse and mitigate the risk of catastrophic damage in the short term.

At individual irrigation systems, weather stations should be improved, including:

- river flow monitoring systems
- more reliable methods for forecasting floods and low-flow

- risk-based approaches to design (flood and sediment control, design of diversion and intakes)
- research should be carried out to understand upper catchments and evaluate new approaches to infrastructure, including:
    - small-scale and on-farm water storage
    - groundwater use through tube wells, integrated for use in surface irrigation systems
    - lift irrigation in hills and on river terraces.

It is also important to improve water management (at system and farm levels) with the use of appropriate operating rules; improve agricultural practices; and strengthening institutional arrangements for river basin management.

Agents (i.e. individuals/organisations) have an important role to play and are expected to promote understanding of climatic and other changes, their impacts, and coping mechanisms in the context of irrigated agriculture, and to make better use of short-term and seasonal forecasts of water availability and floods, and adapt crop and water management decisions accordingly.

1. Introduction

About 1.7 million ha of Nepal's cultivated land is irrigable, of which about 75% has been provided with some irrigation infrastructure and about two thirds of which, in turn, is actually irrigated during the monsoon season.[2] About 30% can be irrigated during the winter season, but only about 18% of the total cultivated land receives year-round irrigation. The country's irrigation policy splits irrigation into four size categories: major, large, medium and small.[3] It is estimated that about 75% of the irrigated areas (about 900,000 ha) are under small- and medium-scale schemes, which are the focus of this project.

Irrigation plays an important role in crop production in Nepal. Nepal relies on subsistence agriculture and low-input, low-output farming systems, characterised by the general integration of crop production with livestock rearing, providing some farm inputs such as manure for soil fertilisation. The extent of this integration varies with altitude and agro-ecological zone. In the hills and mountains, integration is still strong, while in the Terai and river valleys, farm machinery is gradually replacing animal power.

Paddy (rice), maize and wheat are the main cereal crops cultivated in Nepal, but production is variable because of diverse local climates and agro-ecological conditions. Rice and maize are grown under irrigation in limited areas. Cash crops are also grown, including potatoes, oilseeds, pulses, vegetables and fruits.

1.1 Key challenges facing the irrigation sector in Nepal

Several studies and experts suggest that climate change will have adverse impacts on water resources and on agriculture in general, in South Asia in particular.[4,5] This has been confirmed for Nepal as well,[6,7] and its impacts on small and medium-scale irrigation systems are already visible.[8]

Small-and medium-scale irrigation systems are common in the hills and river valleys of Nepal. Most of them are fed from rivers, as there are no storage facilities and water shortages are already occurring. Many of these systems were developed by farmers for over a century. They draw water from adjoining small (often seasonal) tributaries of the major rivers whose discharge relies mainly on rainfall. In the past, these tributaries used to supply an adequate amount of water to their respective command areas, but they are now reported to be drying up. Traditionally, they were used for rice cultivation, particularly to enable timely planting and to protect against dry periods during the monsoon season. Operation of these small systems is vulnerable to changes in livelihoods, population growth and local governance system. In the 1980s, the Government of Nepal started intervening in small- and medium-scale irrigation systems. However, despite the long history of government support in rehabilitation, improvement and modernisation, the performance of small- and medium-scale irrigation systems has yet to be improved. The situation has worsened with the impacts of climate change.[9]

Threats posed by climate change include drought resulting from decreasing dry season flows, and floods due to anticipated high-intensity erratic rains. It is also likely that the distribution and intensity of rainfall will continue to change, leading to greater shortages of irrigation water in some places or at particular times of year. Although the projected increase in temperature is likely to mean more water from snow melt, this is less relevant to small- and medium-scale irrigation, which is predominantly rainfed. Temperature will also increase crop water requirements and will affect crop choice and productivity.[10]

There is a general consensus among researchers that the impacts of climate change on agricultural systems are already visible, with overall decline in production.[11,12,13,14] This change will certainly influence local livelihoods. Although it is difficult to quantify the magnitude of climate change impacts, it has been estimated that the total economic loss associated with such change in agriculture alone will be equivalent to around 0.8% of current annual gross domestic product (GDP) per year.[15] Thus, the impact of climate change on irrigation deserves serious attention.

1.2 Rationale for this project

The performance of irrigation systems is deteriorating,[15] but there is inadequate knowledge about the scale of the impact in small- and medium-scale irrigation systems. The key question is: how can these systems be developed so that they absorb the shocks and stresses induced by climate change and extreme events, and also adapt and transform with the change process? This project, therefore, aimed to analyse the impacts of climate change and develop a framework for improving the resilience and effectiveness of small- and medium-scale irrigation systems in Nepal.

1.3 Research objectives

The overall objectives of the research were to:

- improve the approach and methodology for planning and delivering efficient, effective, equitable and climate-resilient irrigation systems
- assess processes, institutions and policy for irrigation development, management and resource governance

- prepare a framework to increase the climate resilience and effectiveness of small- and medium-scale irrigation systems
- ensure the framework is understood by the relevant governing and implementing parties.

2. Methodology

The study followed a two-pronged approach – top-down and bottom-up (Figure 2.1). These are presented briefly below.

2.1 Review of literature, climate scenarios and policies

The top-down approach focused on understanding Nepal's climate vulnerability and the overall performance of its irrigation sector, including challenges and opportunities. The broader picture of the climate factors was developed through analysis of existing climate data and literature, and projections of climate change for alternative emission scenarios and timescales fromCMIP5.[17,18] The foundation for the study was a review of existing evidence, climate models and literature to assess current and projected impacts of climate change on small- and medium-scale irrigation systems; analysis of irrigation database;[19] and review of relevant policies and programmes. The top-down approach helped develop broad knowledge on irrigation performance from the perspective of climate change.

2.2 Institutional capacity mapping

There is also a need to identify the institutions that are directly linked to irrigation. Hence, institutional capacity mapping was carried out. The organogram (Figure 2.2) shows the irrigation-related organisations with primary and secondary responsibilities.

Given the findings from the field and keeping in view the environmental, institutional and governance mode diversity of Nepal, it was decided to collect information using a bottom-up approach to understand climate vulnerability and performance of irrigation systems at field level.

2.3 Reconnaissance study

First, a reconnaissance of 17 systems was conducted in various geographical and agro-ecological zones in 2015 (Figure 2.3). For this, different types of irrigation systems were selected in terms of their size (small, medium), system characteristics (hill, river valley, Terai), infrastructure (temporary, permanent) and institutional management (strong and weak). Table 2.1 presents the characteristics of the systems studied.

Figure 2.1. Methodological framework

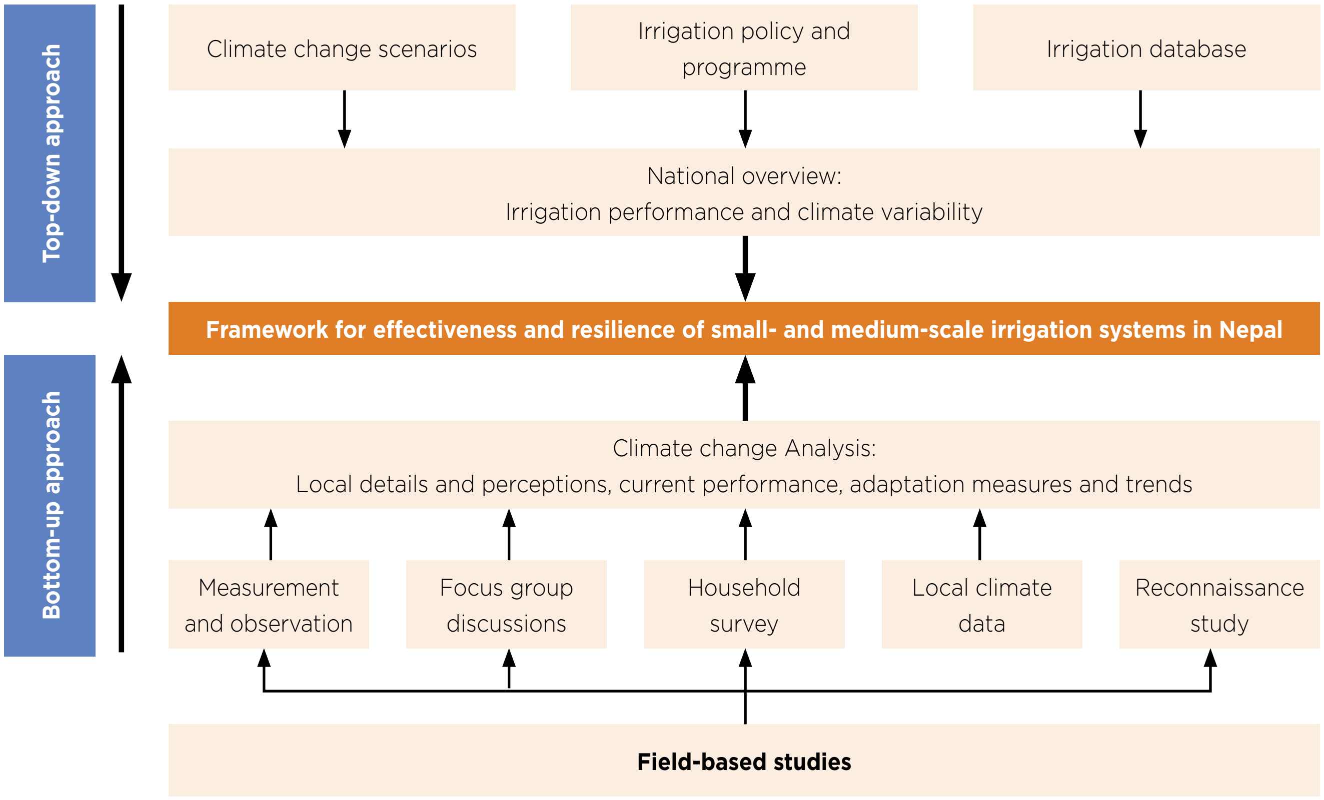
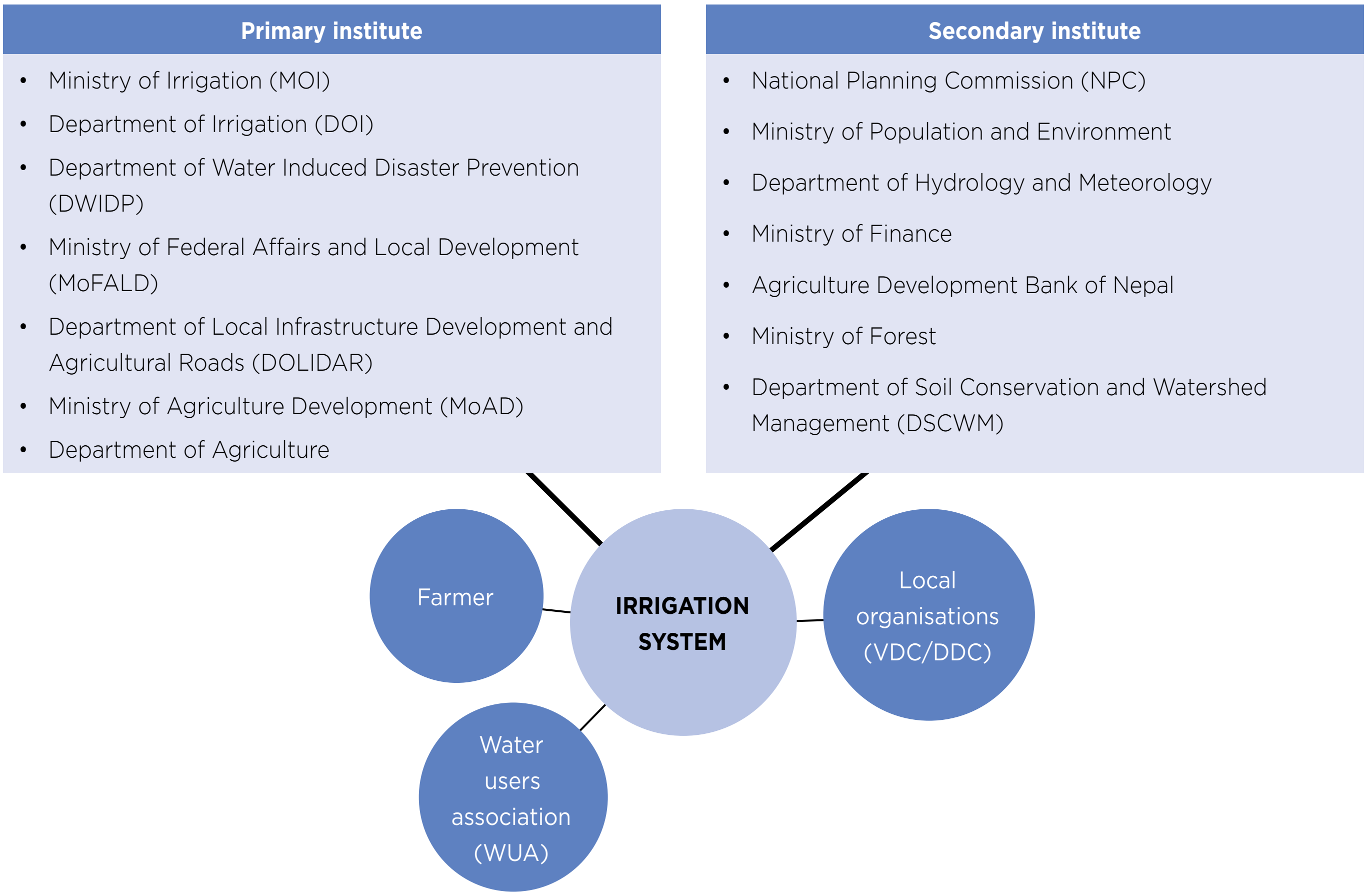


Figure 2.2. Major government organisations involved in the irrigation sector



Primary institute

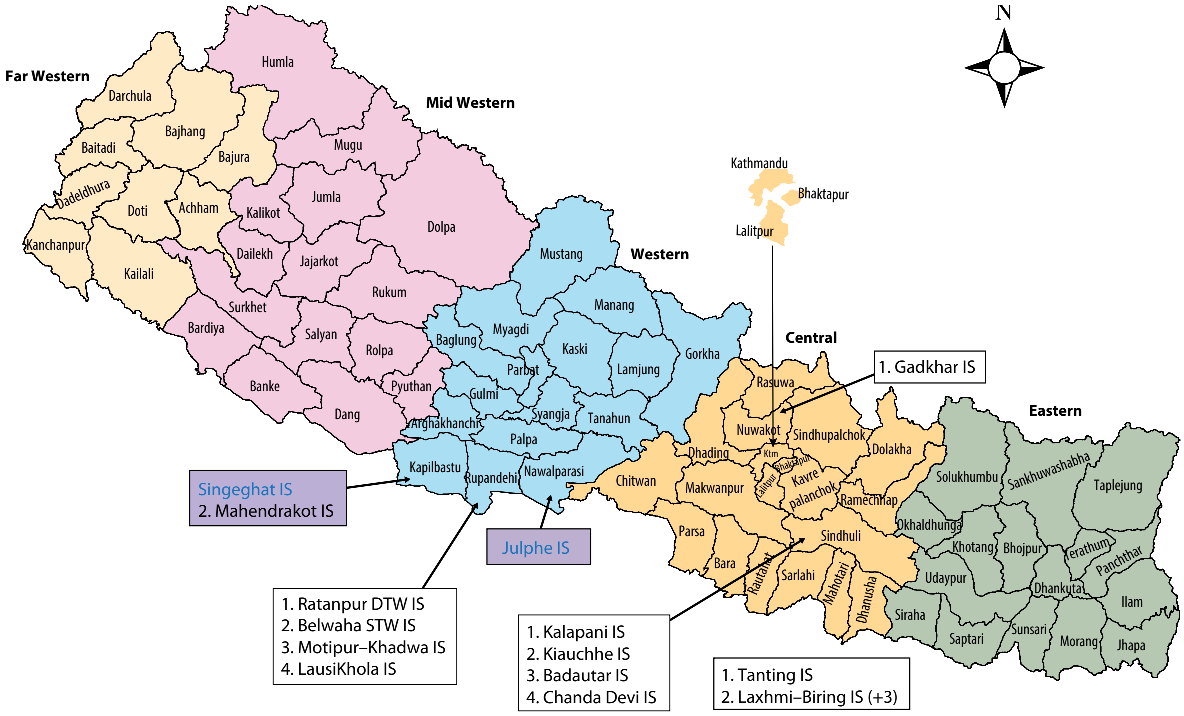
- Ministry of Irrigation (MOI)
- Department of Irrigation (DOI)
- Department of Water Induced Disaster Prevention (DWIDP)
- Ministry of Federal Affairs and Local Development (MoFALD)
- Department of Local Infrastructure Development and Agricultural Roads (DOLIDAR)
- Ministry of Agriculture Development (MoAD)
- Department of Agriculture

Secondary institute

- National Planning Commission (NPC)
- Ministry of Population and Environment
- Department of Hydrology and Meteorology
- Ministry of Finance
- Agriculture Development Bank of Nepal
- Ministry of Forest
- Department of Soil Conservation and Watershed Management (DSCWM)

DDC, District Development Committee; VDC, Village Development Committee

Figure 2.3. Reconnaissance study sites



DTW, deep tube well; IS, irrigation system; STW, shallow tube well

Table 2.1. Sites for reconnaissance studies

System	District	Latest intervention	Area (ha)	Institution	Intake	Zone	Main crops
Nepane	Sindhuli	1998	210	Weak	Temporary	Hill	Cereal
Kauchhe	Sindhuli	None	24	Good/ informal	Temporary	Hill	Mixed, mostly cereal
Bardautaar	Sindhuli	Before 1997	70	Good	Temporary (no weir)	Hill	Predominantly cereal
Chandadevi	Sindhuli	NA	25	NA	Permanent	Hill	Mixed, especially ginger
Gadkhar	Nuwakot	2014	105	Weak	Permanent	Hill	Mixed
Ratanpur	Rupandehi	NA	400	New/weak	DTW	Tarai	Cereal, cash crops
Belwaha	Rupandehi	2000	25	New/good	STW	Tarai	Vegetable, cereal
Lausi Khola	Rupandehi	2000	400	Weak	Permanent	Tarai	Cereal, cash crops
Char Tapah	Rupandehi	2010	1,200	Strong	Permanent	Tarai	Cereal, cash crops
Singhighat	Kapilvastu	2005	2,500	Strong	Permanent	Tarai	Cereal, cash crops
Mahendrakot	Kapilvastu	2001	430	OK	Permanent	Tarai	Cereal, cash crops
Girwari	Nawalparasi	2003	200	Strong	Temporary	Tarai	Cereal, cash crops
Tanting	Jhapa	2010	200	OK	Permanent plus temporary diversion	Tarai	Maize, rice, mustard, wheat, with some cash crops (betel)
Biring (4 systems)	Jhapa	Ongoing repairs	1,000	Strong	Temporary	Tarai	Maize, wheat, mustard, betel

Source: This study, 2017

DTW, deep tube well; NA, not available; STW, shallow tube well

During the reconnaissance study, several types of quantitative and qualitative data were collected using various tools and techniques, including walk-through, observation, measurement, focus group discussions (FGDs), meteorological records from nearby stations and non-structured interviews. Below are some of the findings drawn from the reconnaissance study.

- Groundwater irrigation is relatively more resilient to climate change than surface irrigation. Thus, tube well irrigation was excluded from the list of viable candidates for detailed study.
- As changes in seasonal water availability is one of the main concerns, the climate change study should examine the entire basin rather than looking at an individual system.
- Climate change induced threats on irrigation are of two types: flooding/flash floods, and changes to seasonal water availability. For irrigation systems (small and medium) located in dry areas, changes in seasonal water availability are likely to have greater effect, whereas flood damage is likely to be a greater risk for major schemes.

2.4 Detailed case study in two basins

2.4.1 Site selection

The following site selection criteria were adopted, partly based on the lessons drawn from the reconnaissance study.

- A basin for detailed study should be a surface irrigation system receiving water from a river with a defined hydrological basin.
- Selected systems should preferably be in western Nepal, where droughts are becoming more frequent.
- Selected systems should have a certain amount of historical data.
- Selected systems should be either small- or medium-scale irrigation schemes.

Using these criteria, Singheghat irrigation system (SIS) of Banaganga basin in Kapilvastu District and Julphe irrigation system of Girwari basin in Nawalparasi District were selected for detailed study. The study also examined the basin as a whole and other irrigation systems within it. These case studies were conducted in close coordination with the Department of Irrigation, with participation of other relevant stakeholders at national and subnational levels.

Photo2.1. Measurement of water flow

Photo2.2. Focus group discussion

2.4.2 Data collection

Both qualitative and quantitative data were collected. The qualitative data collection methods included walk-through of the systems and basins, observations, and interviews with the farmers on water management and their perceptions of climate change. Quantitative data were collected from the meteorological stations of Bhairawa Airport, Patharkot (Kapibastu) and Belwa (Nawalparashi), local stations at the system level established to collect rainfall and temperature data, and water flow in the canal. Participatory approaches were also used: participatory rural appraisal (PRA) of systems, FGDs and household surveys conducted in collaboration with farmers and the water users association of each system. District irrigation officials helped with field data collection. Detailed studies of the selected basins and irrigation systems were conducted over a period of six months, April–September 2016, covering the spring and monsoon cropping seasons.

3. Assessment of climate change in Nepal and impact on irrigation

3.1 Climatic changes in Nepal

Temperature and precipitation are two key climatic variables influenced by climate change. Climate change is predicted to affect seasonal water availability, which could have serious impacts on irrigation,[20] and consequently on Nepal's overall economy.

Temperature

Department of Hydrology Meteorology (DHM) data suggest that the temperature across most of Nepal has shown an increasing trend of up to 0.55°C per decade.[21] Other studies have indicated trends of 0.27°C per decade (1975-2006)[22] and 0.4°–0.6°C per decade (1976-2005).[23] Despite these differences, all suggest that temperature in Nepal is increasing at a faster rate than the global rate of warming reported by the Intergovernmental Panel on Climate Change (IPCC)[24] of 0.12°C per decade from 1951 to 2012.

Although average annual temperatures are important for agriculture, subtle indicators – like increasing numbers of warm days and nights, and decreasing numbers of cold days and nights, particularly in the hills – are equally important.

Precipitation and monsoon

Studies on precipitation do not reveal clear or consistent trends: some studies indicate a decrease and others suggest an increase in mean annual precipitation.[25,26,27] However, none of these projections is statistically significant. Further, precipitation data exhibit high seasonal and inter-annual variability.

The precipitation patterns in Nepal are highly influenced by the South Asian/Indian summer monsoon circulation which traverses the country between June and September. According to the Contribution of Working Group II to the Fifth Assessment Report of the IPCC,[28] the Indian summer (south-west) monsoon is known to have undergone abrupt shifts during the past millennium, giving rise to prolonged and intense droughts. Recent observations in Nepal suggest that drought is becoming more frequent, particularly during the winter months and in the western Tarai (which is generally drier than eastern Nepal).[29]

According to records maintained by the Department of Hydrology and Meteorology (DHM) in Nepal, the normal date of the onset of the south-west monsoon is 12 June.[30] Whilst there is no significant trend in the monsoon arrival, several studies show that the monsoon duration is increasing and the withdrawal date is becoming later.[31,32]

In terms of precipitation extremes, Saraju et al. (2008)[33] found an increase in the number of extreme precipitation days at the majority of stations (particularly for stations below 1,500 metres) and highlighted the implications for landslides, flash floods and inundation. There is also some evidence that the number of consecutive dry days or length of dry spells is increasing, whereas the number of consecutive wet days or maximum length of wet spells is decreasing.[34] The occurrence of such erratic rainfall events with no decrease in total annual precipitation increases the possibility of climatic extremes like irregular monsoon patterns, droughts and floods.

Regional variation within Nepal

Nepal's diverse topography and range of ecological zones means that the overall impact of climate change is likely to differ spatially across the country (Table 3.1).

3.2 Climate projections

Projections of national average climate change for specific levels of global warming using climate scenarios from the Representative Concentration Pathways (RCPs) and Special Report on Emissions Scenarios (SRES) groups result in warming of up to 4°C above the 1961-1990 baseline value. Whilst it is currently difficult to get a clear picture of precipitation change due to large model uncertainties, forecast analysis indicates that the annual precipitation change will be in the range of –30% to +30% in March–April–May, –10% to +50% in June–July–August, –20% to +60% in September–October–November and –30% to +10% in December–January–February for a 2°C temperature rise, which is an appropriate time horizon for small- and medium-scale irrigation systems. Increases in rainfall intensity are expected to be of the same order as increases in magnitude of precipitation.

These data suggest that the monsoon precipitation (May–September) is likely to intensify, indicating a corresponding increase in the risk of extreme rain events with decline in winter precipitation.

3.3 Impact of climate change on irrigation

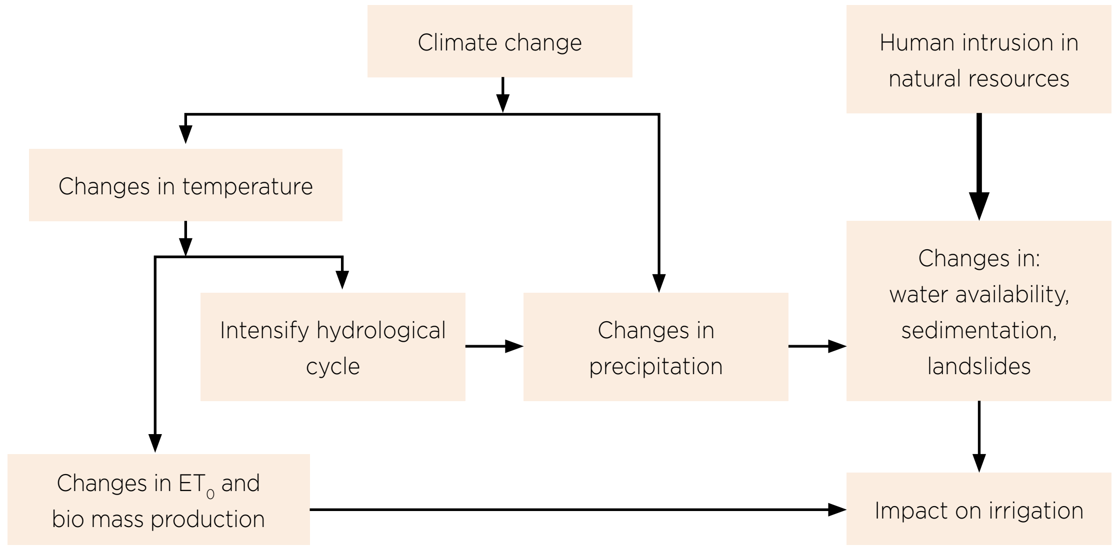
The impact of climate change on irrigation will be of two types: direct and indirect. Likely changes in crop water demand and biomass production are the direct impacts, while likely changes in water availability will have indirect impact. Other than climate change, human intrusions in natural resources also influence water availability, which in turn influences irrigation performance. Figure 3.1 presents a conceptual framework of the impact of climate change on irrigation.

Table 3.1. Regional trends of annual precipitation and maximum and minimum temperature

Region	Max. temperature trend (°C/year)			Min. temperature trend (°C/year)			Precipitation trend (mm/year)		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Terai	-0.02	0.05	0.02	-0.01	0.04	0.02	-14.9	19.8	-1.3
Siwalik	-0.02	0.07	0.02	-0.03	0.05	0.01	-16.3	26.8	0.6
Middle Mountain	-0.01	0.11	0.04	-0.04	0.05	0.01	-35.0	28.7	-2.3
High Mountain	0.02	0.07	0.05	-0.03	0.05	0.01	-42.5	31.1	0.2
High Himalaya	0.04	0.06	0.05	-0.01	0.02	0.01	-6.1	17.2	6.6
Country	**-0.02**	**0.11**	**0.04**	**-0.04**	**0.05**	**0.01**	**-23.0**	**24.7**	**0.7**

Source: Nepal Hydrological and Meteorological Research Centre and Consultancy (2015)[35]

Figure 3.1. Climate change and impact on irrigation



ET_0, reference crop evapotranspiration

4. Case studies of the irrigation systems

4.1 Physical setting

Both the Girwari and Banaganga rivers originate in the Mahabharat Mountains. And both become wide river valleys of the inner Terai, supplying waters to wide tracts of cultivated lands through several small- and medium-scale irrigation systems mostly located north of the east-west highway, with a few to the south of the east-west highway. These irrigation systems in these areas date back centuries.

Girwari River supplies six separate, but adjacent systems, irrigating about 1,000 ha on both banks of the river from where it emerges from the Hills to the east-west highway. Of these systems, Julphekulo is the largest and is the focus of this study, but relations between systems and overall management of the sub-basin are increasingly important because of the growing demands for, and declining supply of, water. Downstream of Girwari, 10 more irrigation systems irrigate the southern part of the sub-basin as far as the confluence with the Narayani River. The upper six systems abstract all the surface water from the river at critical times, but water re-emerges 5–10 km further downstream and can be abstracted to irrigate the southern area.

The Singheghat irrigation system (SIS) of the Banaganga basin was originally divided into 11 *mauja*, each with an independent canal and temporary water diversion weir at the Banaganga River. Irrigation in each *mauja* used to be managed by a water manager (*badghar*) who was elected or selected each year and was in charge of local public works activities, including irrigation and water management. In 2006, these 11 canals were integrated into one system through the construction of a concrete weir and a new main canal, 4.5 km long, to feed the existing canals of the *mauja* via proportional dividers in accordance with their traditional water shares.

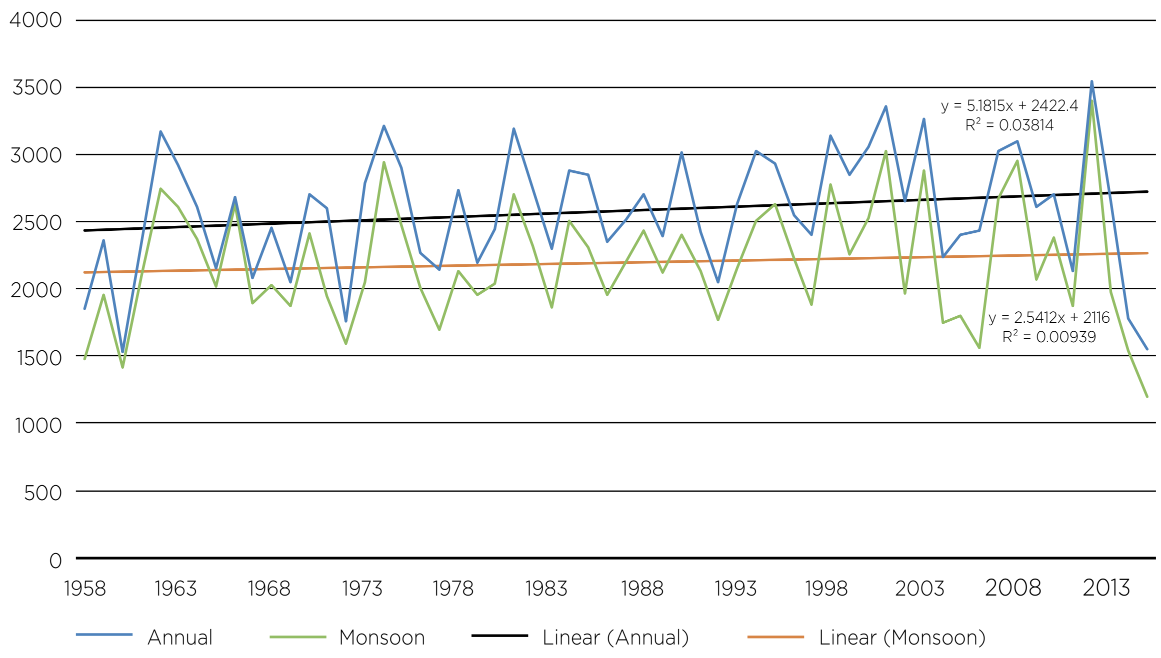
4.2 Climate data

Rainfall was recorded at each site, and then compared with long-term data of the nearby meteorological station. Analysis of long-term data suggests that the average annual rainfall has not changed significantly over the period studied, though there may be several short-term fluctuations (extreme events) which may or may not be the result of climate change.

FGDs among the farmers were conducted in both systems. Farmers perceive that rainfall is decreasing significantly, but this may reflect an overall shortage of water, as the irrigation system only provides part of their needs. Further, farmers' perceptions on rainfall may also have been derived largely from their assessment of how well it meets agricultural needs for water (especially crop water requirements). This is supported by following facts.

- Although rainfall intensity can be expected to increase, and thus the proportion of total rainfall that is effective,

Figure 4.1. Rainfall trends (1955-2015) in Beluwa, Girwari



Source: DHM data

there is little sign that this has happened so far. However, days with smaller amounts of rain (up to 50 mm) are a decreasing trend (Figure 4.2) – though this may not be significant.

- A week-long dry spell in the month of September is increasing. The September rainfall is critical because the flowering and grain-formation stages of paddy fall in this month.

4.3 System management

In Girwari, although the six systems are operated independently, various coordination arrangements have been set up, especially for the spring season, resulting in each system receiving water in turn on about a 10-day cycle. During the monsoon, systems can be operated continuously with ad hoc arrangements during times of intermittent rainfall. As irrigation is supplementary to rainfall, such dry periods both create additional demands and reduce the water availability in the river. Hence, the farmers of these different systems decided to work together to meet their water requirements through water distribution by rotation.

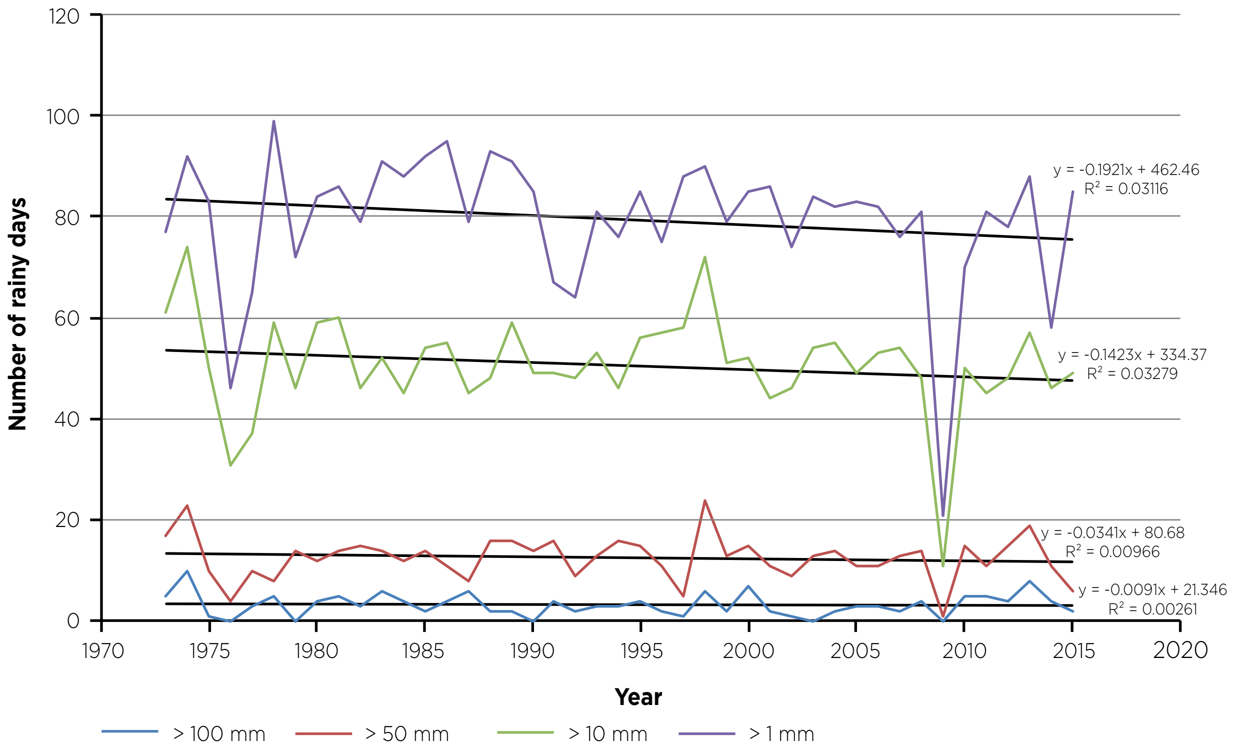
The Singheghat irrigation system (SIS) diverts all the surface water from the river through its concrete diversion weir at critical times. SIS has adopted continuous water supply or rotation on the basis of water availability. The Water Users Association (WUA) has elaborate regulations for water distribution among the individual canals and within villages. Another lesson to be learned is that the rehabilitation must now be undertaken with consideration for the watershed conditions and the implications for downstream water users. There is clear evidence of water use conflict downstream of the SIS.

4.4 Availability of flows

There is general consensus that the availability of water in the river, especially during the dry season, has decreased significantly in the recent past. In Girwari, the minimum flow recorded in April/May 1982 was 310 litres/second (l/s),[36] whereas a flow of 90 l/s was measured in April 2016 against the estimated natural minimum river flow of about 400 l/s.[37]

Likewise, the minimum flow recorded in the Banaganga River in 1980 was 600 l/s,[38] whereas in May 2016 the minimum flow measured upstream of the Banaganga barrage was about 240 l/s against estimated flows of 1,470 l/s in accordance with the hydrological assessment method recommended by the Water and Energy Commission Secretariat (WECS) at the DHM, Government of Nepal. This indicates that available minimum flow at the intake of Banaganga irrigation scheme has reduced by about 50% over three decades. This suggests that more than half of the potential run-off is now being

Figure 4.2. Rainfall characteristics at Pathakot (close to Banaganga)



Source: DHM data

used in the upper catchments of these systems, while the proportion used in the upper catchments three decades ago was very minor.

As with the river, there is a strong local perception that the available flows in canals are also decreasing significantly. To verify this perception, the main canal flows were measured upstream of the main proportioning weir of the Julphe irrigation system in Girwari, and compared with flows measured in 1997 at the same locations. Figure 4.3 presents a comparison of these flows at one such location.

These figures suggest that, over the season, canal flow was reduced to half of that recorded in 1997. This 50% level of loss is consistent throughout the course of the main canal (i.e. at all three measurement locations), suggesting that management remains strong, and that farmers have been able to cope with the deteriorating situation using adaptation measures.

4.5 Floods

There is a general perception that the incidence of instantaneous peak floods in these rivers is increasing, with intense rainfall recorded on 22 July, 26 August and 1 September 2016. These caused high sediment flows into the canals, washed out[39] the intake of the Akasekulo (irrigation system) of Girwari system, and damaged downstream protection of the Singheghat weir (Figure 4.4).

As the flood overtopped the Singheghat weir, it was not possible to operate the gates at the peak of the flood, but considerable damage would have been avoided if the canal gates had been closed as the flood was rising. This incident highlights the need to ensure that designs include adequate safety factors including free board, and to ensure that there are appropriate operating rules and that the structure is operable under peak design conditions.

4.6 Irrigation management

In Singheghat, the construction of the weir and other control structures has improved both the reliability of water delivery and the efficiency of system operation. It is also possible to manage very low flows in ways which would not have been possible before. This is a valuable lesson for coping with water shortage more widely. There is, however, a negative impact of the weir on downstream users, outside the formal (water rights) boundaries of the Singheghat canals, who used to benefit from the uncontrolled flows that passed into and through the system.

In Girwari, there has not been any major change in irrigation management for along time, though some adjustments to the distribution system and rotational arrangements have been made to enhance irrigation efficiencies. Water distribution has remained fairly equitable and reliable.

Declining availability of flow in canals is a major problem in both systems. Water availability is usually well below

Figure 4.3. Canal flow at Julphe upstream of main proportioning weir (field study)

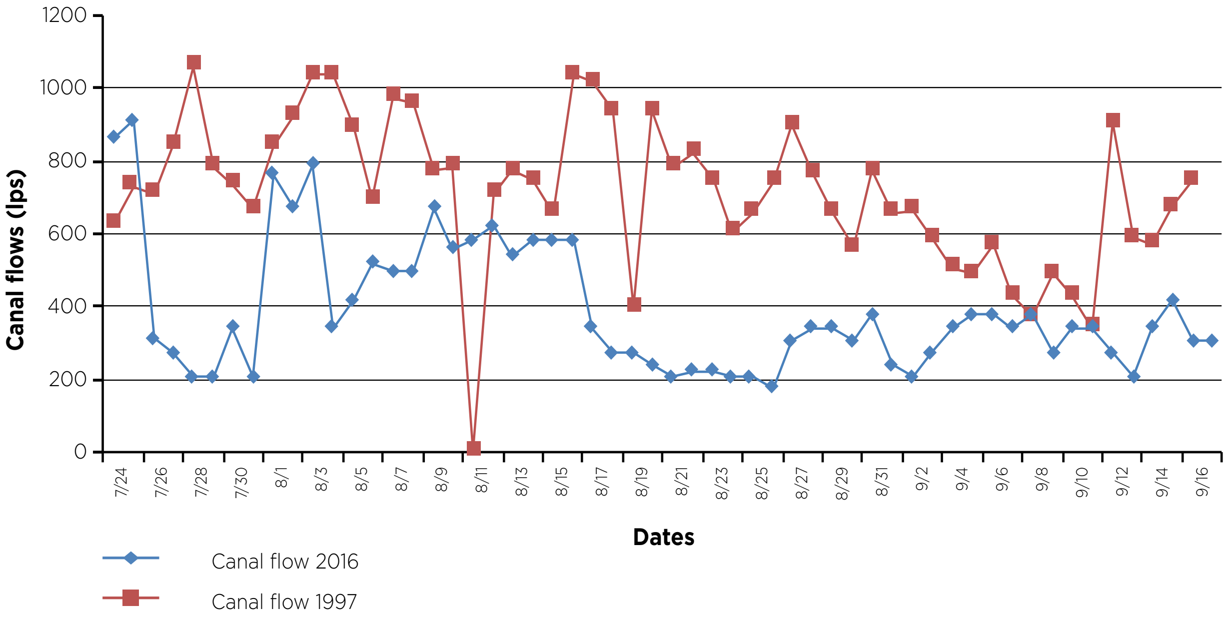


Figure 4.4. Flood damage of intake and weir

demand, even when rainfall is included. As a result, farmers tend to divert the maximum possible water from the canal, which in turn is shaped by rainfall in the watershed (Figure 4.5).

There is a close relationship between rainfall and canal flows –with canal flows (a reflection of drawdown from the river) increasing as it rains, rather than being curtailed due to less demand. To cope with the declining water availability, farmers in both systems are installing tube wells for groundwater extraction.

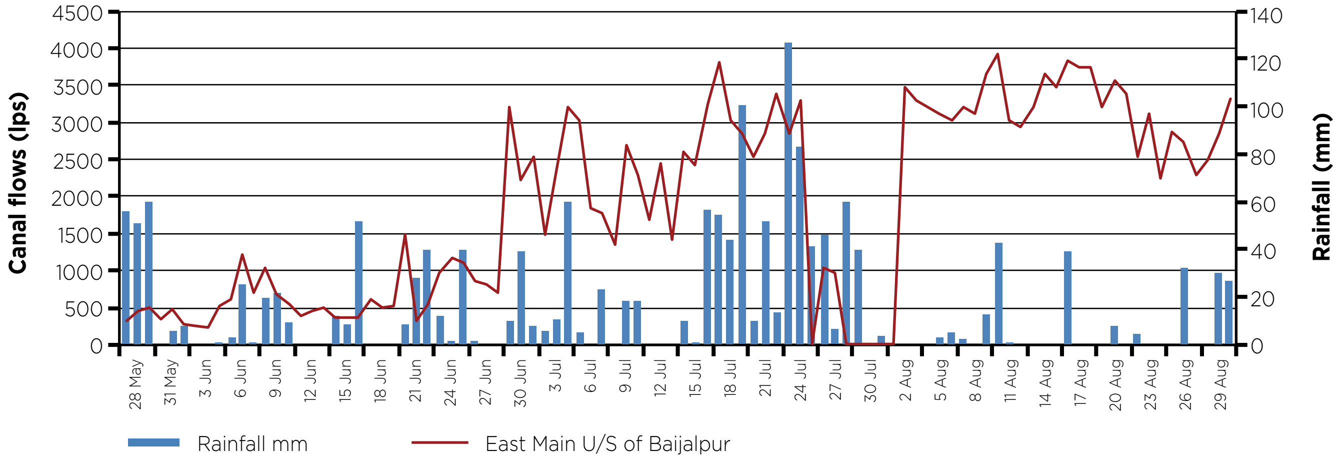
4.7 Non-climatic factors that impact on agricultural production

During FGDs, farmers highlighted out-migration of youths from the village as a problem causing shortage of labour in agriculture. Increased urbanisation has taken place, taking over agricultural land for housing in the irrigation command area. The cash economy has brought many non-agricultural activities to the villages. Another big threat to irrigation systems is sand and boulder mining. The impacts can be seen downstream of Singheghat and Girwari. Similar cases are reported in almost all river systems – bringing adverse impact to irrigation systems by dislocation of irrigation water supply. There is, therefore, a need to look into the possible adverse impacts on irrigation system management from both climatic and non-climatic factors.

4.8 Local adaptation

Both the Girwari and Singheghat systems have been adapting to change over the past 50 years, with water availability dropping to about 50% of the natural flow for

Figure 4.5. Rainfall in the command area versus main canal flows of the Singheghat irrigation system (East)



Source: Field study

various reasons. Adaptation has been achieved through a combination of strong institutional arrangements supported by investments in infrastructure.

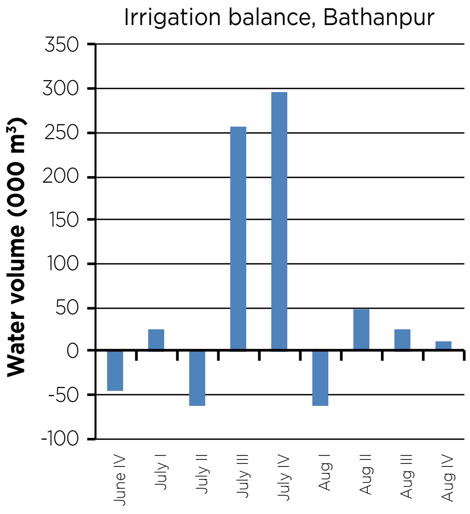
Some of the local-level adaptations are as follows.

- Institutional strengthening at both watershed and system levels.
- Infrastructural improvement: The provision of a weir at Singheghat has improved the acquisition of water from the river even during low flows, and protected the system from the impact of riverbed quarries. However, downstream systems are still vulnerable.
- Augmentation of water sources: In both systems, water sources have been augmented through the installation of tube wells.
- Acceptance of higher levels of risks to crop cultivation by adapting deficit irrigation. With the declining availability of water, farmers are cultivating crops under deficit irrigation (see Figure 4.6).
- Adjusting cropping patterns and crop scheduling: There are many cases of farmers adjusting cropping patterns and schedules. One such case is cultivating early ripening short-duration varieties of paddy to match the demand for and supply of water and, presumably, to increase yield.

5. Making the irrigation systems resilient

Climate change is felt and experienced by the farmers of the irrigation systems and the study revealed how climate change has impacted irrigation systems and is likely to do so in future. It is vital to act immediately to make the irrigation systems resilient to unprecedented changes, including climate. Resilience is an evolving concept in irrigation: it is highly contextual and varies greatly from one location to another. The IPCC definition of resilience is “the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity of self-organization, and the capacity to adapt to stress and change”.[40] Resilience is understood to be the ability to anticipate, avoid, plan for, cope with, recover from and adapt to (climate-related) shocks and stress.[41]

Figure 4.6. Irrigation balance, Bathanpur branch, Singheghat irrigation system



Source: Field study

The resilience of irrigation systems (i.e. irrigation communities and irrigation agencies) can be understood as the ability of the systems to adjust in response to changes. Irrigation systems may have strong absorptive capacity leading to persistence (capacity to absorb); adaptive capacity, leading to incremental adjustments and adaptation (capacity to adapt); and anticipatory capacity, leading to proactive and transformational responses in the face of expected and unexpected changes (capacity to anticipate).

The study proposed a framework (Figure 5.1) with the main factors that influence resilience. The framework shows how climate change affects vulnerability (to both shocks and trends) and systems features – institutions, agents and government agencies that interact with each other. The study also identified important factors that need to be considered in systems, institutions and agencies to strengthen resilience (Table 5.1).

6. Summary and recommendations

6.1 Summary

There has been a change in climatic factors in Nepal. Temperature has increased. Although no change in the annual rainfall amount has been recorded, the pattern has shifted so that it is out of synchronisation with harvest times and thus the usefulness of rainfall for crop cultivation is decreasing. Water availability for irrigation is declining. There is evidence of increasing peak flows. River morphology is changing rapidly. These changes have resulted in increased risk of declining crop yields although there are several non-climate change factors that are equally responsible for the compounded negative impacts on the irrigation sector.

Along with other factors, climate change has increased the vulnerability of the irrigation systems and it is likely that the systems will be even more vulnerable in the future under the predicted climate scenarios. Thus, it is important to start making the irrigation systems more resilient as a matter of urgency, so that they can absorb the current stress and shocks, be adapted for change, and transformed for longer-

Figure 5.1. Framework for resilience

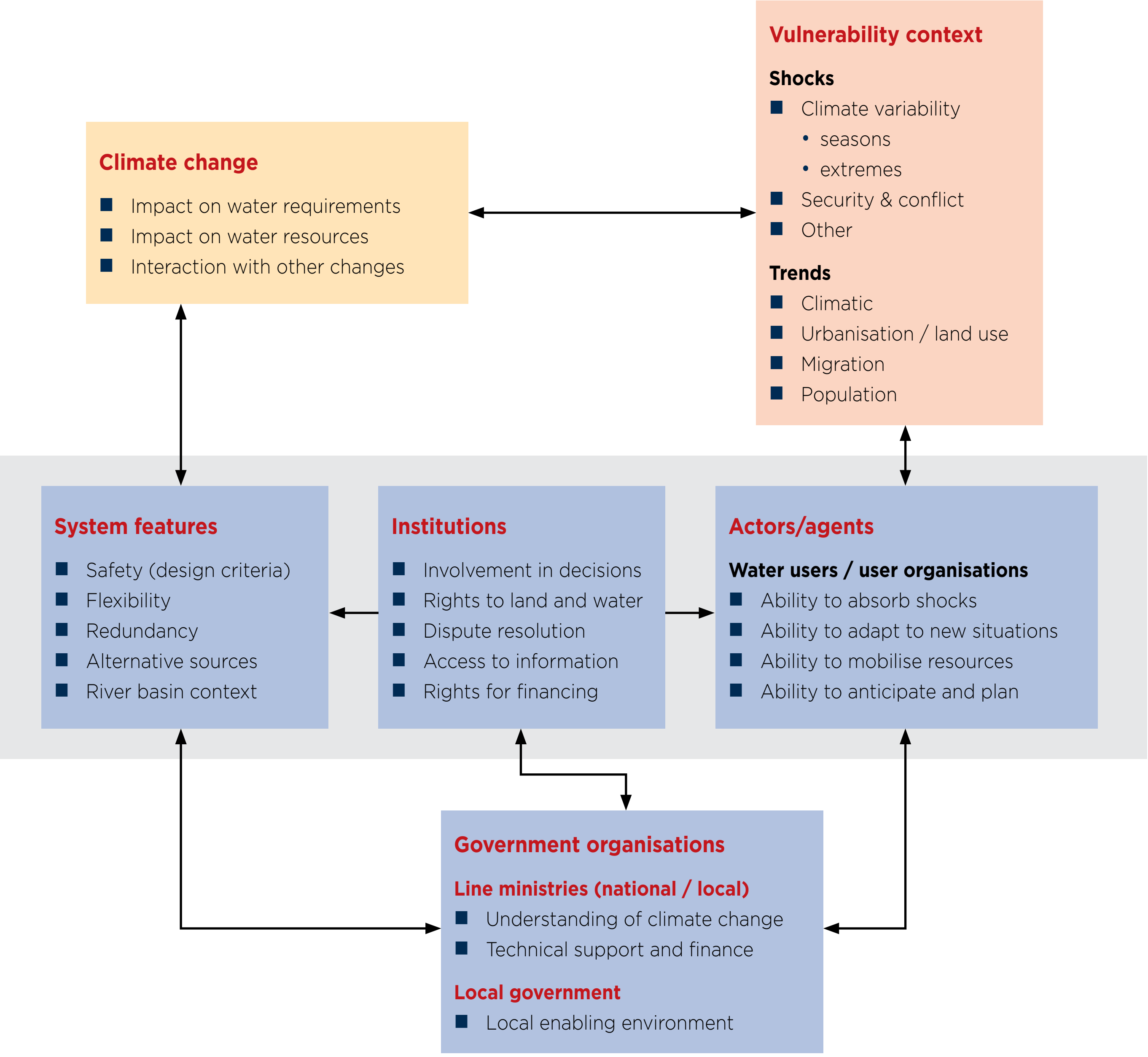


Table 5.1. Important factors for promoting resilience

Systems	Institutions (rules)	Agents (individuals, organisations)
• Modified design criteria. • Flood capacity – exclusion of peak floods, safe escape structures and fuse plugs, protection of vulnerable canal reaches. • Control of water at low flows, through time rotation and rationing of water. • New irrigation delivery systems. • Development of new sources, with integration of groundwater and surface water management.	• Arrangements for cooperative management of natural resources, including riverbed materials as well as water. • Water rights (actual and implied) across the river basin – to avoid causing adverse impacts. • Land rights, reflecting new livelihood patterns. • Mechanisms for preventing and resolving conflicts. • Ability to raise finance and other resources. • Markets and subsidies for crops.	• Farmers' ability to absorb, adapt to and anticipate change, in addition to existing climate uncertainty and other non-climatic changes. • Access to knowledge, willingness and resources to adapt or diversify agriculture and livelihoods more widely.

term uncertainty and change. It is also vital to address the resilience issues at individual farmer, community and irrigation organisation levels.

To improve the resilience of irrigation systems, the role of stakeholders – especially the government – is central. Various factors have to be strengthened to improve systems, institutions and agency (see Figure 5.1 and Table 5.1 for details). The role of the Department of Irrigation in particular is critical in building climate-resilient irrigation systems.

Improvement of agricultural support services is important to enable diversification of crops and proper crop cycle planning to improve water use efficiency. For this, catchment-level management is required to manage supply and demand in both upstream and downstream systems.

6.2 Recommendations for climate-resilient development

The smaller the basin the more sensitive it is to change. With most irrigation dependent on small catchments, adaptive management is essential. Actions in one area may have negative impacts in other areas, so it is recommended that any changes are carefully monitored and introduced incrementally as they are needed. Sensitivity tests can be carried out to analyse and mitigate the risk of catastrophic damage in the short term. The following are recommended.

At irrigation system level

- Climate data collection stations should be improved, at least for key parameters (minimum and maximum temperatures, daily rainfall), with river flow monitoring introduced in representative small basins.
- More reliable methods should be derived for flood and low-flow forecasting in unmonitored catchments, along with estimation of effective rainfall.
- Research should be undertaken on the impact of soil and water conservation in upper catchments, including small-scale water harvesting.
- Risk-based approach to design should be introduced, with improved procedures for:
  - design of diversions and intakes, particularly for flash floods in the rivers and streams that drain the Siwalik Hills (outer Himalayas)
  - flood and sediment control at permanent intakes
  - consideration of lift irrigation to reduce the need for long vulnerable canals in the hills
  - management of low flows, diversified cropping, crop water requirements and delivery mechanisms for winter and spring cropping.

Evaluation of new approaches to infrastructure, including:

- lift irrigation in hills, and on river terraces and plains in the foothills (tar)
- provision and use of small-scale and on-farm water storage
- groundwater from tube wells integrated with surface irrigation systems.

At institutional level

- Water management should be improved (at system level and on farm), with the use of appropriate operating rules.
- There should be a value chain approach to agricultural development, linking producers to markets, and addressing constraints at all levels.
- Institutional arrangements for river basin management should be developed and strengthened.

At agent level

- Actions should be taken to promote understanding of climatic and other changes, their impacts, and coping mechanisms in the context of irrigated agriculture.
- Better use should be made of short-term and seasonal forecasts on water availability and floods, and crop and water management decisions should be adapted accordingly.

Endnotes

1. This document is based on: Mott MacDonald (2017) *Framework for effectiveness and resilience of small- and medium-scale irrigation: RSAS 0017 Final report*. Cambridge: Mott MacDonald (https://ferinepal.files.wordpress.com/2017/04/01_rsas0017_final-report.pdf). The authors of this report were the members of the study team, as detailed in that publication.
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9. One of the reasons for their poor performance is that the government interventions focused solely on replacing temporary infrastructure with more permanent infrastructure without examining their management from the broader perspective of governance, socioeconomics and climate change.
10. There may be some benefits as well as adverse impacts, such as higher yields due to higher temperatures and carbon fertilisation. Projections of future change are highly variable according to location, scenario and model.
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19. CERD (2007) Op. cit.
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Project study team: This project was led by Mott MacDonald, UK working with the Farmer Managed Irrigation System Promotion Trust (FMIST), the Centre for Engineering Research and Development (CERD), and the ADAPT-Nepal in conjunction with the Department of Irrigation. The team included:

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- Ram Hari, FMIST
- WUAs and the water users of concerned irrigation systems

The study was guided by a Project Advisory Committee, comprising

- Mr. Sushil Chandra Tiwari, Ministry of Irrigation, Chairman,
- Mr. Akhanda Sharma, Ministry of Population and Environment
- Mr. Shiva Nepal, Department of Hydrology and Meteorology
- Dr. Madhab Paudyal, Department of Agriculture,
- Dr. Ram Chandra Khanal, CDKN

About this document: This policy brief synthesises the findings and recommendations from the project and is intended for policy-makers, planners and implementers working in Nepal's irrigation sector under uncertain conditions induced by climate change. It provides guidance to irrigation sector project designers and policymakers on assessing climate risks at the project and system levels, and on mitigating the risks using the resilient approach

More detailed descriptions on the study methodologies, case studies, climate analysis, and major findings are covered in the technical reports of the project.

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