Towards Conjunctive Use of Surface Water and Groundwater Resources as a Response to Water Access Challenges in the Western Plains of Nepal

Cereal Systems Initiative for South Asia

Funded by

Partners

CSISA COVID-19 Resilience Activity Partners

Towards Conjunctive Use of Surface Water and Groundwater Resources as a Response to Water Access Challenges in the Western Plains of Nepal

Vishnu Prasad Pandey[1,2], Anupama Ray[2,3], Manohara Khadka[2],
Anton Urfels[4,5,6], Andrew McDonald[7], Timothy J. Krupnik[8,9]

1. Department of Civil Engineering, Pulchowk Campus, Institute of Engineering, Tribhuvan University, Chakupat, Lalitpur 44600, Nepal
2. International Water Management Institute (IWMI) - Nepal, Shree Durbar Tole, Lalitpur 3, Pulchowk, Kathmandu, Nepal
3. Centre of Research for Environment Energy and Water(CREEW). Baluwatar, Kathamandu - 4, Nepal
4. International Maize and Wheat Improvement Centre (CIMMYT), South Asia Regional Office, Khumaltar, Lalitpur, Nepal
5. Water Resources Management Group, Wageningen University and Research, Wageningen, Netherlands
6. Centre for Crop Systems Analysis, Wageningen University and Research, Wageningen, Netherlands
7. Section of Soil and Crop Sciences, School of Integrative Plant Sciences, Cornell University, Ithaca, NY, USA
8. CIMMYT, South Asia Regional Office, Khumaltar, Lalitpur, Nepal
9. CIMMYT- Bangladesh. House 10/B. Road 53. Gulshan-2. Dhaka, 1213, Bangladesh

CSISA

Cereal Systems Initiative for South Asia

The CSISA Nepal Covid-19 Response and Resilience Activity

Intensive cropping systems that include rice, wheat and/or maize are widespread throughout South Asia. These systems constitute the main economic activity in many rural areas and provide staple food for millions of people. Therefore, enhancing the yield and productivity of cereal production in South Asia is therefore of great concern. Simultaneously, issues of resource degradation, declining labor availability and climate variability pose steep challenges for achieving the goals of improving food security and rural livelihoods.

www.CSISA.org

The Cereal Systems Initiative for South Asia (CSISA) was established in 2009 with a goal of benefiting more than 8 million farmers by the end of 2022. The project is an exemplar exampleof One CGIAR in action, and is led by the International Maize and Wheat Improvement Center (CIMMYT) and implemented jointly with the International Food Policy Research Institute (IFPRI), the Inernational Water Mangement Institute (IWMI) and the International Rice Research Institute (IRRI). Operating in rural 'innovation hubs' in Bangladesh, India and Nepal, CSISA works to increase the adoption of various resource-conserving and climate-resilient technologies, and improve farmers' access to market information and enterprise development. CSISA supports women farmers by improving their access and exposure to modern and improved technological innovations, knowledge and entrepreneurial skills. CSISA works in synergy with regional and national efforts, collaborating with myriad public, civil society and private-sector partners.

CSISA's Goals

- Facilitate the widespread adoption of resource-conserving practices, technologies and services that increase yields with lower water, labor and input costs.
- Support mainstreaming innovations in national-, state- and district-level government programs to improve long-term impacts achieved through investments in the agricultural sector.
- Generate and disseminate new knowledge on cropping system management practices that can withstand the impacts of climate change in South Asia.
- Improve the policy environment to facilitate the adoption of sustainable intensification technologies.
- Build strategic partnerships that can sustain and enhance the scale of benefits accrued through improving cereal system productivity.

With a new investment in the CSISA program, the USAID Mission in Nepal is supporting CSISA to rapidly and effectively respond to the threats posed by the COVID-19 crisis that undermine the recovery and sustained resilience of farmers in the FtF Zone of Nepal. This Activity includes Texas A&M University, Cornell University, and International Development Enterprises (iDE) as core partners. Activities involve two inter-linked Objectives that address CSISA's strengths in core areas needed to assist in COVID-19 response and recovery over an18 month period (From July 2020- December 2021). The ultimate goal of the CSISA COVID-19 Resilience Activity is to develop mechanisms to support longer-term resilience among smallholder farmers and the private sector – with emphasis empowering youth and overcoming challenges faced by women headed farm households. At the same time, the Activity is assisting in efforts to increase smallholder farmers' understanding of, and capacity to protect themselves, from COVID-19. This is achieved through the dissemination of awareness raising messages on public health and by increasing economic opportunities for return migrants, smallholder farmers, and by encouraging resilience-enhancing irrigation.

Suggested citation:

Pandey, V.P., Ray, A., Khadka, M., Urfels, A. McDonald, A., Krupnik, T.J. (2021). Towards Conjunctive Use of Surface Water and Groundwater Resources as a Response to Water Access Challenges in the Western Plains of Nepal. The Cereal Systems Initiative for South Asia (CSISA). Kathmandu, Nepal.

Printed in Nepal. Published in 2021

Acknowledgements:

This work was supported by the Bill and Melinda Gates Foundation and USAID through the Cereal Systems Initiative for South Asia (CSISA). The views and opinions in this document are those of the authors and do not necessarily reflect the Gates Foundation or USAID and shall not be used for advertising purposes. We greatfully acknowledge Sumona Shahrin for assistance with adapting and impriroving figures,

Executive Summary

While food security in Nepal has improved in recent years, nearly 4.6 million people remain food insecure. Inadequate access to irrigation results in sub-optimal land and water productivities that pose key constrains to improving farmers' livelihood and food security. At present, only 48% of the net cultivated area in Nepal has irrigation of some kind, however, only 39% of cultivated area has year-round-irrigation (YRI). However, due to unreliability of supply and/or high operational costs, even areas recorded under irrigation coverage have access to limited water. Though it may not be feasible to bring all arable land under irrigation for various reasons such as non-viability of irrigated area expansion for field crops in much of Nepal's hills, groundwater resources in alluvial aquifers in the Terai, which are underdeveloped and can – if carefully planned and implemented – be utilized for expanding irrigation coverage. Emerging evidence also indicates that the percentage of irrigated area could be substantially increased, especially with groundwater or conjunctive use (CU) of groundwater and surface water. Conjunctive use is already practiced in many irrigation command areas, in part because of poor maintenance and unreliable supply of surface water schemes that have caused farmers to supplement surface water with groundwater. Nonetheless, initial estimates suggest that roughly 88% of the groundwater that could be abstracted on a sustainable basis in Nepal is yet to be utilized. Under such circumstances, expanding CU approaches has some potential to improve access to reliable irrigation. This could lead to productivity enhancements of land and water resources while providing a practical pathway for improving livelihoods and food security. As such, CU can be considered as an option to get the most out of existing surface water infrastructure, while recognizing that meaningful expansion of surface water use with the construction of new canals and canal structures is unlikely due to very high investment costs and questionable performance in terms of reliable access to water in many existing surface water schemes. To assess its prospects, CU planning requires, a detailed understanding of the availability and spatio-temporal distribution of surface water and groundwater resources, and multi-sectoral water demands.

This study considers six Terai districts within the Feed the Future Zone of Influence (FtF-ZoI) in Western Nepal as study area. We aim to answer the following research questions by means of a thorough review of available literature to provide inputs for developing a sustainable framework for irrigation development considering – i) What are the estimates on current and future water availability in the FtF-ZoI? ii) What are estimates on current and future water demand? iii) What are prospects and potential strategies for planned CU in the FtF-ZoI (Terai districts)?

This research is part of a larger effort to develop a framework for sustainable irrigation development in the FtF-ZoI considering biophysical issues as well as socioeconomic, policy, and institutional concerns, complemented by futuristic scenario modeling of irrigation development options. This document therefore informs these efforts and provides guidance on key hydrological concerns pertaining to irrigation development. A summary of key findings from the current documents on various dimensions that indicates prospects for conjunctive use (CU) planning in the FtF-ZoI region (Terai districts) is provided hereunder.

I. Water development initiatives

- **Water development projects/programs:** A large number of water resources development projects/ programmes are implemented by the government of Nepal in collaboration with development partners and research institutions. Some of them are focused on research for development while others on implementing the development activities for service delivery. Some examples of the notable projects or programmes that include FtF-ZoI region include Prime Minister Agriculture Modernization Project (2016-2026), value chain for inclusive transformation of agriculture (VITA, 2020-2026), community irrigation project (CIP, 2010-2018), small irrigation programme (SIP, 2015-2020), Digo Jal Bikas Project (DJB, 2016-2019), PAANI (2016-2021), Local Infrastructure for Livelihood Improvement (LILI, 2006-2009), Irrigation and Water Resources Management Project (IWRMP, 2008-2018), and Non-Conventional Irrigation Project (NITP, started in 2003).
- **Status of irrigation development:** Formal irrigation infrastructure in the Terai is designed to provide access to about 310,260 ha of land within Nepal's FtF-ZoI districts. The area under irrigation is likely to be larger than this because many privately installed pumps and groundwater-based command areas are not registered or documented in official statistics. However, overall scope for irrigation development remains far larger than the area provided with irrigation facilities from public as well as private sectors. In response, this study aims at identifying the area which has potentially much larger scope of irrigation development. Out of the total irrigated areas, surface irrigation systems are designed to cover nearly 72% of total irrigated land through 231 irrigation systems (with > 10 ha and 25 ha command areas in hill and Terai, respectively), whereas irrigation coverage from official groundwater wells in Terai is only 26%.

Official groundwater irrigation coverage varies across the FtF-ZoI districts (Terai only) from 13% of total irrigated area (or 9,740 ha) in Bardia to 53% (or 24,248 ha) in Kanchanpur. This shows that there is a good potential for further irrigation expansion using groundwater. Out of total areas irrigated by groundwater, 85% area is supplied with water from shallow tube well (STW) and the rest from the deep tube well (DTW). Estimates of well drilling obtained through communication with private well drillers are in the order of 5,000 irrigation wells and 16,000 domestic wells per year for the FtF-ZoI districts (Terai only). This strongly suggests that large parts of groundwater development are undocumented because they have been installed using private funds by individuals or groups of farmers. There is consequently a need for a census of irrigated area in Nepal, which not only accounts for all areas irrigated – even in small command areas – but that also distinguishes between types of irrigation (e.g., surface, ground, or CU) and identifies the source of investment (e.g., privately installed groundwater wells, diversions or catchment from rivers and canals, or formal surface water schemes supported with public funds) supporting irrigation development.

- **Status of knowledge generation**: Fifty-four articles from the scientific and grey literature were identified that synthesize varying aspects of knowledge on water resources, agricultural, and water infrastructure development in the FtF-ZoI districts in the Western Nepal. Most of the scientific literature is related to water availability assessment, flood forecasting and inundation mapping, flood risk assessment, and early warning systems. However, robust literature with quantitative information on CU is almost non-existent.
- **Data/information gaps:** Some key gaps in data/information include non-availability of geospatial data on abstraction point and its attributes such as quantity as well as command areas for groundwater irrigation systems; no documentation on current status of CU, limitations and learnings from planned CU; no information on performance of existing irrigation systems (both surface and groundwater), including their status, currently served command area, water losses and inefficiencies, and potential to rehabilitation for translating into year-round-irrigation (YRI).
-

II. Water availability

- **Surface water availability:** We retrieved 20 articles that report surface water availability in one or more river systems/sub-systems that provide water resources within the FtF-ZoI region. The parameters reported in the literature for a river basin/sub-basin includes catchment area, baseline discharge, average annual volume of water available, projected future change in water availability, and water balance components. Key hydrological features are available for the Karnali, Bheri, Seti, Tila, Upper Karnali, Mohana, Chamelia, West Rapti and Babai river systems. However, level/extent of information available varies widely across the basins. Specific discharge across the nine river systems varies from 18.8 l/s/m2 (Upper Karnali, at Lalighat hydrological station) to 52.1 l/s/m2 (Mohana, above the confluence with the Karnali river at Nepal-India border).
- **Groundwater availability:** Renewable groundwater resources in Terai are the result of recharge from the northern edge of the Terai, the Bhabar Zone, along the Siwalik foothills, percolation of rainfall in the Terai plains, and discharge from rivers during high flow periods. Though a clear delineation of groundwtaer recharge areas for groundwater system in the Terai region within the FtT-ZoI is yet to develop, availability of renewable groundwater resources estimated based on water-balance approach using SWAT hydrological model indicates that the districts with decreasing groundwater availability in terms of million cubic meters (MCM) per km2 per year are Kanchanpur (0.48), Kapilbastu (0.42), Bardia (0.38), Banke (0.33), Kailali (0.26), and Dang (0.11). Furthermore, deep aquifer yield is the highest in Bardia district (32 lps), followed by Kanchanpur (28 lps) and Dang with relatively lower yield (only 15 lps).
- **Data/information gap:** Comprehensive modeling and scenario assessment of entire hydrological system (both surface and groundwater) that cover all areas within the FtF-ZoI region using a coherent method and approach is lacking. Though there are estimates of different time periods, using different approaches and models, that are not always constrained to the FtF-ZoI in particular. Furthermore, a detailed hydrogeological characterization of aquifer systems and their spatial distribution across the FtF-ZoI region; location of groundwater monitoring wells; and assessment of sustainable yield from different locations within the aquifer are not well documented in published literature.
-

III. Water demand

- Some useful information that can help estimate water demands such as total areas under agriculture as well as areas under major cereal crops (i.e., rice and wheat), and areas under surface irrigation system within the FtF-ZoI region are documented in the literature. However, there is no comprehensive study report on estimates of water demands and their spatio-temporal distribution within the FtF-ZoI. Some studies that have estimated approximate values of domestic and irrigation water demands are scattered across different locations but none cover the entire areas of FtF-ZoI. Therefore, it's hard to map water demand hot-spots, overlay with water availability (both surface water and groundwater) distribution, and draw meaningful information in terms of CU planning.

- For available estimates of water demands, a detailed description on methods and assumptions used in current studies are not well documented. The lack of clear description of methods calls into question the validity and robustness of some of these studies, indicating uncertainty and highlighting a crucial knowledge gap in the FtF-ZoI region.
- There are no estimates on projected future water demands (irrigation, domestic, etc.), neither in basins nor in command areas or district or Palika levels.
- Finally, though Irrigation Master Plan (2019) has documented inventories of surface water use, inveotry of use of groundwater resources, along with their location (latitude, longitude), and associated details are conspicuously absent in the available literature. Similarly, data on water and environmental flows in these systems are not publicly accessible.

IV. Conjunctive use (CU) planning

- **Prospects for planned CU:** A 15-questions framework for assessing CU prospects was designed and applied to assess CU prospects in the FtF-ZoI districts (Terai only) in the Western Nepal[1]. Co-existence of both surface water and groundwater, under-utilization groundwater resources so far, and unreliable or inadequate water supply from surface water system that draws water from rain-fed and spring-fed rivers indicate a good prospect for planned CU in the FtF-ZoI districts (Terai).
- **Challenges for planned CU:** Challenges as well as impediments for promoting more rational CU planning and subsequent implementation in the FtF-ZoI districts (Terai) are mainly related to technical capacity, socio-political realities, inadequate emphasis on research-based development practices, data/information gaps, and promoting research and its communication to a wider range of stakeholders.
- **Potential strategies for planned CU**: Translating huge prospects for planned CU in the FtF-ZoI districts (Terai) into reality requires strategies, mobilization of actors and resources, and political commitments as elaborated in Section 5.3. They include but not limited to promoting solar and/or hydropower driven groundwater irrigation; design and implement monitoring system (both water resources and demands) with adequate spatial and temporal resolution; raising awareness through long-term strategic programs; adequate investments in hardware (system modernization and improved infrastructure) and software; research for development; improving water use efficiency; designing and implementing programs aimed at enhancing recharge; incentivizing programs that enhance profitability of agriculture sector; and harmonization of policies and programs; and creating atmosphere for private-public partnership. Some of the specific recommendations could be promoting open hydrological data system to address the data gap; participatory mapping to deal with data scarcity; and coupling these recommendations with existing and planned initiatives.

[1] This document focuses largely on the Terai as this is the most agriculturally intensive area in Nepal with significant scope for improved management and environmentally sound expansion of irrigation water use. That said, where appropriate, attention is also directed at the hills and mountains of Nepal where they constitute hydrological linkages. A lack of available data from these areas and inability to conduct field work due to the COVID-19 crisis limited data collection and hence inference on the situation in the hills.

Table of Contents

List of Tables

List of Figures

Acronyms and Abbreviations

AET	Actual Evapotranspiration
AFMIS	Agency-Farmer Managed Irrigation System
AMIS	Agency Managed Irrigation System
BBDMP	Bheri-Babai Diversion Multipurpose Project
CBS	Central Bureau of Statistics
CIP	Community Irrigation Project
CU	Conjunctive Use
DJB	Digo Jal Bikas
DJF	December-January-February
DOA	Department of Agriculture
DoED	Department of Energy Development
DTW	Deep Tube well
DWRI	Department of Water Resources and Irrigation
DWSSM	Department of water supply and Sanitation Management
FAO	Food And Agriculture Organization
FF	Far Future
FMIS	Farmer Managed Irrigation System
FtF	Feed the Future
GCA	Gross Command Area
GDC	Groundwater Development Consultant
GDP	Gross Domestic Product
GESI	Gender Equality and Social Inclusion
GoN	Government of Nepal
GW	Giga Watt
GW	Groundwater
GWRDB	Groundwater Resource Development Board
ha	Hectare
IBWTP	Inter Basin Water Transfer Project
ICIMOD	International Centre for Integrated Mountain Development
IFDA	International Fund for Agriculture Development
IGP	Indo-Gangetic Plain
IMP	Irrigation Master Plan
IWUAs	Irrigation Water User Associations
JJAS	June-July-August-September
KISAN	Knowledge-Based Integrated Sustainable Agriculture in Nepal
LILI	Local Infrastructure for Livelihood Improvement
LIS	Lift Irrigation System
lps	litres per second
MoALD	Ministry of Agriculture and Livestock Development
MAM	March-April-May
masl	Mean sea level
mbgl	Meter Below Ground Level
MCM	Million Cubic Meter
MF	Mid Future
Mg/l	Milligram per litre
mm	Millimeters
MPP	Multipurpose project
MW	Mega Watt
NEA	Nepal Electricity Authority
NCA	Net Command Area
NF	Near Future
NPR	Nepalese Rupee
NWY	Net Water Yield
ON	October-November
PMAMP	Prime Minister Agriculture Modernization Project
ppb	Parts Per Billion
RCP	Representative Concentration Path
SDG	Sustainable Development Goals
SIP	Small Irrigation Programme
STW	Shallow Tube well
SW	Surface Water
SWAT	Soil and Water Assessment Tool
TBM	Tunnel Boring Machine
TW	Tube Well
USAID	United States Agency for International Development
VDC	Village Development Committee
VITA	Value Chain for Inclusive Transformation of Agriculture
WECS	Water and Energy Commission Secretariat
WHO	World Health Organization
WL	Water Level
WRPPF	Water Resources Project Preparatory Facility
WRS	Water Resource Strategy
WUAs	Water Users Associations
YRI	Year-Round Irrigation
ZoI	Zone of Influence

1. Introduction

1.1 Context and need of the study

Food and nutrition security are among the key policy objectives for many governments across the globe. It is true for Nepal as well. Despite decline in poverty level of Nepal by almost one-third since 1995, Nepal is struggling to produce sufficient food (IMP, 2019). While food security in Nepal has improved in recent years, 4.6 million people are still food insecure (MoH-GoN/New Era/IFC, 2017). Food insecurity in Nepal arises from constraints in agriculture inputs, sub-optimal productivity, inadequate access to irrigation, and lack of integrated management of water and land resources (Nepal et al., 2019). Despite being the second largest contributor to Nepal's economy, with agriculture sector growth of 2.9% compared to 4.7% growth in gross domestic product (GDP) between 2008 and 2018, agriculture sector, engaging over 60% of the population in the country, contributes only 27% to GDP thereby reflecting poor productivity of the sector (IFAD, 2020). To achieve 10% growth in GDP, agriculture sector needs to grow by at least 6% (DoA, 2018). It is possible through improving productivity by several means, including increasing cropping intensity, which, as per IMP (2019) is currently far below the potential of 200%. One of the problems of agriculture sector which needs due attention is the lack of adequate irrigation facilities (IMP, 2019). At present, only 48% of the net cultivated area in Nepal has irrigation of some sort, but only 39% of cultivated area has year-round-irrigation (YRI) (IMP, 2019). Therefore, it's necessary to identify all possible pathways for enhancing access to irrigation water and prioritizing investments accordingly. Conjunctive use (CU) of both surface water and groundwater could be one of those pathways because it can increase water security, improve water use efficiency, and ultimately contributes to increasing water productivity as well as other benefits such as flood management as elaborated in **Chapter-5**.

Only about 48% of cultivated land in Nepal has irrigation facilities of which 59% are irrigated from surface water, 22% from groundwater, and 19% from CU (IMP, 2019). This CU is primarily unplanned, i.e., farmers supply additional water from groundwater source where surface irrigation system is not able to supply sufficient water for irrigation. The is difference between planned and unplanned groundwater use as shown in **Box 1-1**. More than half of cultivated land is rain-fed. The Terai, the food basket of the country stretching from the East to West in the southern plain of the country, has nearly 60% of cultivated land with access to irrigation (IMP, 2019). Most irrigation in Terai are from groundwater (Urfels et al., 2020) and some are via canals that take water from small and medium-size rivers which dry up during winter and summer. On the other hand, energy constraints (or high cost, e.g. in case of diesel pumps) limit the ability of farmers to pump groundwater (Nepal et al., 2019). Despite having a large reserve of groundwater, its contribution to total irrigation in the Terai region is only 26% (IMP, 2019). Groundwater resources in alluvial aquifers in Terai are underdeveloped. It is estimated that 88% of the groundwater that could be abstracted on a sustainable basis is not utilized, providing ample space for increased groundwater use for productivity enhancement in irrigation (Urfels et al., 2020). Under these circumstances, achieving an ambitious plan of reaching YRI from present 39% to 55% by 2025, 66% by 2030 and 100% by 2045, as outlined in the national Irrigation Master Plan (IMP, 2019), is possible only through planned CU in the Terai region of the country. It, however, requires a detailed understanding of availability and spatio-temporal distribution of surface water and groundwater resources, water demand, and assessing prospects for planned CU.

> ***Box 1-1: Planned and unplanned groundwater use***
>
> **Unplanned Groundwater Use:** Groundwater use by individuals or a small group of users for various purposes by drilling their own wells, which are generally not accounted in national statistics. Many households in Terai drill wells or hand pumps and use groundwater for various uses, including irrigation. They are unplanned groundwater use.
>
> **Planned Groundwater Use:** Groundwater development and use for a relatively larger command area through government's initiative and funding, ideally with participation of communities. They are accounted in national statistics of water use.

Feed the Future Zone of Influence (FtF-ZoI) covers 21 districts (six in the Terai and the rest in hilly areas) including 237 Palikas[2] within three provinces (Lumbini, Karnali, and Sudurpaschim) in the Western Nepal (**Figure 1-1**). FtF-ZoI is one of the key regions in the country that has potential to contribute in doubling the growth through productivity optimization. This region is home for around 6.9 Million people, nearly 21% of them are living under poverty (FTF, 2016).

[2] Palikas are local government units either rural municipality or municipality as per the new political governance system of Nepal

Figure 1-1: Location of the Feed the Future Zone of Influence districts in Western Nepal. Focal districts (i.e. Terai districts) are shaded with grey.

Both surface water and groundwater resources are available (mainly in Terai districts) to meet the water demands. Surface water resources are available in five major river systems as shown in Figure 3-1. They are Mahakali, Karnali, Mohana, Babai and West Rapti. The Karnali and Mahakali are perennial snow-fed rivers whereas are others originating in Chure or Mahabharat range are rain-fed and spring-fed rivers. The FtF-ZoI in the Terai is affected by climatic stresses in the form of variable precipitation, drought and heat stress thereby limiting the productivity of the farming systems in the region. One of the ways to address the issue could be sustainable utilization of available water resources through planned conjunctive use (CU).

1.2 Objectives

This study has the goal of assessing prospects for planned CU and potential strategies for to realize it in the FtF-ZoI districts (Terai only) located in the Western Nepal. Three specific objectives to achieve the goal are –

i) To assess current and future water availability,

ii) To evaluate current and future water demands, and

iii) To assess prospects for planned CU in the FtF-ZoI districts (Terai) and potential strategies for planned CU.

The outputs of this study are expected to be useful for planners and policy makers of the government agencies to get insights for informed policy-making and planning towards sustainable use of available water resources (both surface water and groundwater). This will eventually contribute towards more equitable distribution of such resource development and socioeconomic benefits.

1.3 Methodological approach

The methodological approach for the analysis consists of three components, namely, assessing water availability, assessing water demand, and evaluating prospects for planned CU to develop a sustainable framework for irrigation development in the study region (Figure 1-2). All analysis is based on systematic review of literature and synthesis based on available secondary data/information.

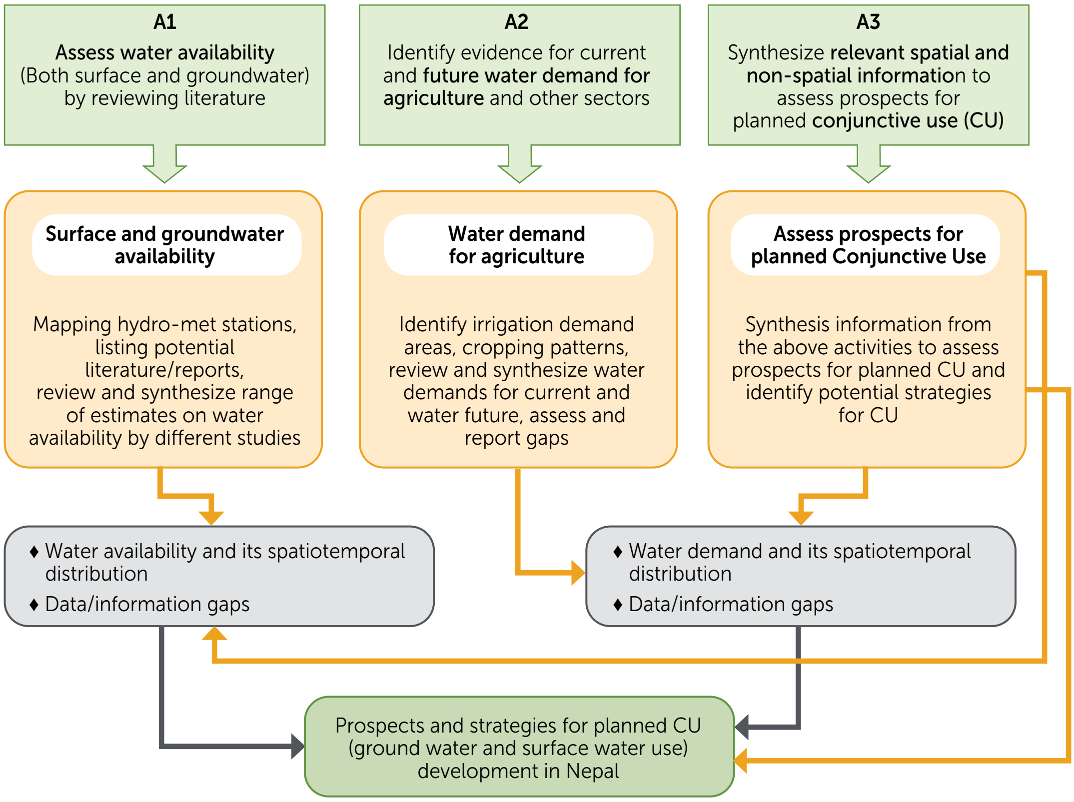


Figure 1-2: Methodological framework adopted in this study

Literature identified through a defined process were reviewed to assess current and future water availability, water demand, and prospects for planned CU. Details on literature identification, screening, review of literature, and types of data extracted from the literature, for each component (water availability, demand, and identifying prospects for CU) are elaborated in respective chapters.

The results will be used for developing a sustainable and inclusive framework for irrigation development in Terai through planned CU. Relevant data were collected from those literature, tabulated appropriately, and analysed in terms of total water availability and demand, and their spatio-temporal distribution.

1.4 Structure of the report

The report is structured under six chapters, references, and annexes. This introduction chapter is followed by **Chapter 2** that elaborates various water development initiatives in the FtF-ZoI districts, mainly focusing on water resources assessment and development programs/projects, status of irrigation development, and state of knowledge generation. **Chapter 3** describes water availability assessment, focusing on both surface water and groundwater resources, and also describes data/information gap. **Chapter 4** synthesizes the findings from review of water demand assessment. Prospects for CU planning as well as potential strategies are well elaborated in **Chapter 5**, which if followed by Conclusions (**Chapter 6**). At the end, there are a list of references and annexes.

2. Water Development Initiatives

There is a long history of water development initiatives in the FtF-ZoI region in the form of studies, programs, projects, and publications. To synthesize those initiatives, relevant literature was identified, screened, and reviewed in detail in a systematic way. The existing and planned water development projects in the FtF-ZoI area were searched in google with following keywords: irrigation project, Western Nepal, Karnali basin, Hydropower project, water supply project, and water development programme. The information regarding projects was also explored in the respective website like Water Resources Project Preparatory Facility, Bheri Babai diversion Multipurpose Project, Department of Energy Development (DoED), Nepal Electricity Authority, WECS, Department of water supply and Sanitation Management (DWSSM). Various project-related websites in both Nepali and English were also explored for update news of the project. Such web portals include but not limited to My Republica, The Rising Nepal, Digo Jal Bikash (Sustainable Water Development), and Prime Minister Agriculture Modernization Project. Some grey literature (e.g. reports) were also collected and reviewed. They include the Irrigation Master Plan (2019) and Irrigation Water Use and Inventory (2018). This process resulted identification of 35 such literatures, both articles and reports.

The screening of the literature was conducted by skimming the abstract and the content. Then the literature with contents related to existing and planned water development projects, news updates of the project from different websites, and the report which actually show and provide important information on the water project were selected. Twenty-eight (28) studies were selected after screening the literature. Eight out of them were excluded as they provide only general information for a small area and/or detailed engineering design. Some literature were of other target area and perception-based, some of them were only review and old study so in that case, original and latest reports were followed. Finally, 19 literatures were selected for detailed review and synthesizing information on water development initiatives.

2.1 Water resources development projects/programmes

A large number of water resources development projects/programmes are implemented by the government of Nepal in collaboration with development partners and research institutes. Many of them are related to water supply, sanitation, hydropower, and small-scale irrigation, and therefore, not much relevant to this study. Furthermore, some of those studies are focused on research for development while others are focused on implementing the development activities. **Table 2-1** provides some key features of the selected projects/programs with specific focus on water resources and/or irrigation and following sub-sections elaborates them in brief.

Other notable initiatives by the government of Nepal, in the form of project or programme include, Irrigation and Water Resources Management Project (IWRMP), Non-Conventional Irrigation Technology Project (NITP), Medium Irrigation Project (MIP), and Community Managed Irrigation Agriculture Project (CMIASP). IWRMP project was financed by the Government of Nepal and the World Bank. The project started in 2008 and completed in 2018. The project consisted of four components: i) irrigation infrastructure development and improvement; ii) irrigation management transfer; iii) institutional and policy support for improved water management; and iv) integrated crop and water management. The project contributed to provide year-round irrigation facilities for 73,876 ha of agriculture land with the rehabilitation of schemes under FMIS and AMIS (DWRI, 2018). Similarly, NITP project was established in 2003 to develop and promote other than conventional irrigation technologies and techniques. The project aimed to develop irrigation systems incorporating efficient irrigation technologies for under irrigated areas as well as to areas where conventional irrigation systems are not possible for various reasons. NITP is basically promoting micro irrigation technologies and developing efficient irrigation system for such technologies.

Table 2-1: Water resources development projects/programmes (selected) in the Feed the Future Zone of Influence

S.N.	Name of Programme/ Project	Working Status	Duration	Focus	Target area	Irrigation/ Agriculture /water resource focused	Activities related to irrigation/water resource	Implementing Agency	Donor	Reference
1.	Value Chain for Inclusive Transformation of Agriculture (VITA)	Running	2020/2021-2025/2026 (72 month)	About Value Chain for Inclusive Transformation of Agriculture (VITA).	In 28 districts in States 2, 3 and 5.	Agriculture focused	Small-scale water and irrigation schemes for crops and livestock.	Asia and the Pacific Division Programme Management Department	IFDA, government funding, ADBL and banks, Heifer, beneficiaries and private sector contributions.	IFAD (2020)
2.	KISAN	Running	2017-2022	To increase resilience, inclusiveness and sustainability of income growth through Knowledge-Based Integrated Sustainable Agriculture	Feed the Future Zone of influence	Agriculture focused	Provide appropriate irrigation technology, mainly supplies pumps to surface water schemes and planned outcome is to access irrigation to more than 940 farmer groups.	Winrock International	USAID	USAID website: https://www.usaid.gov/nepal/fact-sheets/kisan-project
3.	Prime Minister Agriculture Modernization Project (PMAMP)	Running	2016-2026	For increasing agriculture production and productivity to make the country self-reliant in agriculture production and livestock within a decade.	Across Nepal. Initiated work in all Terai districts within FtF-ZoI	Agriculture focused.	Provide services of small irrigation infrastructure development, operation and maintenance like repairing and maintenance of small irrigation canal, construction of cemented and plastic lining ponds, concrete ponds construction, drip irrigation, shallow tubewell, motors and pump services, pipe lift irrigation and help with irrigation machinery.	GoN	GoN	PMAMP website: https://pmamp.gov.np/
4.	Digo Jal Bikas	Completed	2016-2019	To promote sustainable water resource development in Western Nepal	Karnali Basin, Mohana sub-basin, Mahakali Basin.	Water resource	Developed hydrological model, E-flow model, policy, GESI.	IWMI	IWMI and USAID.	https://djb.iwmi.org/
5.	PAANI	Running	2016-2021	To enhance Nepal ability to manage water resources for multiple uses and users through climate change adaptation and the conservation of the freshwater biodiversity	Mahakali, Karnali and Rapti river basin	Water resources management	Developing watershed profile regarding status, challenges and opportunities for improved water resource management.	USAID	U.S. Forest Service and the International Water Management Institute (IWMI).	USAID website: https://www.usaid.gov/nepal/fact-sheets/paani-program
6.	Small Irrigation Programme (SIP)	Phase I completed. Phase II planned in Province 1	Phase I: 2015-2020	To build small gravity irrigation systems	4 districts in the west (Achham, Dailekh, Jajarkot, Kalikot) and five in the east, (Khotang, Okhaldhunga, Ramechhap, Sindhuli, Udayapur).	Irrigation focused	Building small gravity irrigation system	GoN	Government of Switzerland and Government of Nepal under Nepal Agricultural Services Development Programme (NASDP)	http://www.sipnepal.org/

Table 2-1: Water resources development.... cont'd

S.N.	Name of Programme/ Project	Working Status	Duration	Focus	Target area	Irrigation/ Agriculture /water resource focused	Activities related to irrigation/water resource	Implementing Agency	Donor	Reference
7.	Bheri-Babai Diversion Multipurpose Project (BBDMP)	Running	2012-2023	To achieve year-round irrigation for 51,000 ha agricultural land and generate 46 MW electricity by inter-basin water transfer	Banke and Bardia districts	Irrigation focused	Achieving year-round irrigation for 51,000 ha of agricultural land	GoN		https://www.bbdmp.gov.np/
8.	Rani Jamara Kularia Irrigation Project	Running	2011-2023	To increase the production and productivity of not only the main irrigated crops, but also vegetables and fruits, by introducing improved technologies and practices and better use of irrigation water	Three municipalities (Tikapur, Lamki-Chuwa, and Janakinagar) in Kailai district, Western Terai	Irrigaton focused	Extend irrigation facility to about 57,320 ha of land, with 38,300 ha for year-round irrigation	GoN	World Bank (for command area development only)	https://aciu.rjkip.gov.np/project-description/
9.	Community Irrigation Project (CIP)	Running	2010-2018	To develop and improve small-scale irrigation systems through a community-driven process targeted to the poor, women, and other disadvantaged groups.	Kanchanpur, Kailali, Dang, Kapilvastu in the Terai plains, Doti, Salyan, Rukum, Rolpa, Pyuthan in the hills, and Bajhang, Jumla, Mugu in the mountains.	Irrigation focused	Irrigation infrastructure development	GoN	ADB, Government of Nepal (GoN) and beneficiaries	CIP (2020) website: http://cip-mis.aviyaan.com/cipweb/
10.	Local Infrastructure for Livelihood Improvement (LILI) Phase II	Phase I completed, Phase II is being studied	2006-2009	To increase the level of income and food security of the remote and food deficit hill areas through supports in small to medium sized farmer managed irrigation systems.	Doti, Achham, Jajarkot and Dailekh in the west, and Dolakha and Ramechhap in the east.	Agriculture/Food focused	Supports in small to medium sized farmer managed irrigation systems.	Scott Wilson Nepal	Swiss Agency for Development and Cooperation (SDC)	Scott Wilson Nepal website: https://swnepal.com.np/project/preparation-of-program-document-of-local-infrastructure-for-livelihood-improvement-lili-phase-ii/.
11.	Sikta Irrigation Project	Running	2005-2015 (but yet to complete)	To irrigate 33,800 ha of agricultural land in the right bank and 9,000 has on the left bank of West Rapti River by diverting water from the river.	Banke district (left and right bank of West Rapti River)	Irrigation focused	To irrigate 42,800 ha of land in both sides of West Rapti River in Banke district	GoN		

2.1.1 Value chain for inclusive transformation of agriculture (VITA)

The VITA programme (IFAD, 2020) is focused on scaling up successful models of inclusive rural growth that have delivered substantial impacts on net farm incomes for small-scale producers and have been recognized for their strong performance in targeting benefits to women and youth alongside facilitating the growth of sustainable local supply chains. The time duration of the programme is five years (75 month) starting from 2020/2021 to 2025/2026. The programme financing is by IFDA (49.6%), government funding (5.1%), ADBL and banks (16.4%), Heifer (3%), beneficiaries (17.1%) and private sector contributions (8.6%). VITA will focus intensive activities in 28 districts in state 2, 3 and 5. State 5 and state 2 have strong agricultural potential combined with highest numbers of people living in poverty. In state 3, the programme is more focused, working in districts with good agricultural potential that were the most severely impacted by the 2015 earthquake. The major outcome of this project is to improve livelihoods, climate resilience and nutrition of poor and vulnerable people by increasing profitable, sustainable agriculture market linkage and using appropriate financial services. To improve the efficiency and enabling environment for the producer groups and supply chain actors, the project will provide targeted investment support to critical supply chain infrastructure such as regional wholesale market, satellite wholesale market, small-scale community infrastructure, including small-scale water and irrigation schemes for crops and livestock (5 ha, each) and upgrading farm access roads (under 10 km each).

2.1.2 Prime Minister Agriculture Modernization Project (PMAMP)

With the realization of agricultural deficient, supply-side constraints, high rate of import, the Ministry of Agricultural and Livestock Development (MoALD) has executed the Prime Minister Agriculture Modernization Project (PMAMP) across the country from 2016. The government of Nepal solely funds this project. The government has introduced the project with a clear and specific roadmap for increasing agriculture production and productivity to make the country self-reliant in agriculture production and livestock within a decade. Under the project, the government has classified the agriculture production sector into pockets, blocks, zones and super zones. Around 10 hectares of land are required for one pocket, 100 hectares for a block, and 500 hectares for a zone and 1,000 hectares for a super zone. PMAMP targets to increase the number of super zones, zones, blocks and pockets to 21, 300, 1,500 and 10,000, respectively by the end of the project. By the end of Fiscal year 2075/76, there are 2776 pockets, 336 blocks, 69 zones and 14 super zones across the country. The time frame of programme is ten years, spanning from 2016 to 2026. This programme's coverage includes all the FtF-ZoI districts in Terai. Under PMAMP programme, as per need, it provides services of small irrigation infrastructure development and operation like repairing and maintenance of small irrigation canal, construction of cemented and plastic lining ponds, concrete ponds construction, drip irrigation, shallow tubewell, motors and pump services, pipe lift irrigation and also help with machinery in irrigation system.

2.1.3 Digo Jal Bikas (DJB)

The overall goal of Digo Jal Bikas (DJB) is to promote sustainable water resource development in Western Nepal by engaging with relevant stakeholders and producing knowledge that supports decision makers in developing policies and plans that balance economic growth, social justice and healthy, resilient ecosystems. The geographic focus of this project are the basins and sub-basins within the Karnali and Sudurpaschim Provinces of Nepal. It includes a particular focus on the Karnali Basin, including the Mohana sub-basin in the Terai and the Mahakali Basin. This project is funded by IWMI and USAID. The time period of project was four years from 2016 to 2020.

2.1.4 PAANI Programme

PANNI Programme is a USAID funded five-year programme starting from 2016 working to enhance Nepal ability to manage water resources for multiple uses and users through climate change adaptation and the conservation of the freshwater biodiversity focusing in 12 watersheds of three river basins Mahakali, Karnali and Rapti in mid and far west Nepal. The program is part of USAID's ongoing investment in strengthening natural resource management in the country. It is a sister project to the USAID-funded Nepal Hydropower Development Project (NHDP) and complementary projects funded by the U.S. Forest Service and the International Water Management Institute (IWMI). Its activities are developing watershed profile regarding status, challenges and opportunities for improved water resource management.

2.1.5 Knowledge-Based Integrated Sustainable Agriculture in Nepal (KISAN)

The United States Agency for International Development (USAID) under its Feed the Future initiative has contracted Winrock International to implement the KISAN Project. Phase I has already completed and Phase II is underway. KISAN II aims to increase resilience, inclusiveness and sustainability of income growth in the Feed the Future Zone of Influence. KISAN II is a five year (July 12, 2017 to July 11, 2022) plan. KISAN II will focus on 20 districts in the West, Mid-West and Far-West regions and four earthquake-affected districts in the Central region. The expected outcomes are increased yield and volumes of selected crops, increased percentage of small holders, farmer cooperatives and farmer associations able to meet market quality, increased value of new private sectors investment in selected agricultural market systems, strengthened institutional and human resource capacity of the GoN and private sector to support market systems development, platform established for collaboration and learning among KISAN II stakeholders. With specific to irrigation, KISAN provides appropriate irrigation technology, mainly supplies pumps to surface water schemes and planned outcome is to access irrigation to more than 940 farmer groups.

2.1.6 Small irrigation program (SIP)

The Government of Nepal in collaboration with the Government of Switzerland has implemented SIP Phase I since February 2015. The objective of this project is to reduce the poverty of small farmer especially the disadvantage group by increasing their agricultural income by building small gravity irrigation system for year round irrigation. The SIP phase I ended in Fiscal year 2076/2077 (July 2019/July 2020). The target area of SIP phase I are in 4 districts in the west (Achham, Dailekh, Jajarkot, Kalikot) and five in the east, (Khotang, Okhaldhunga, Ramechhap, Sindhuli, Udayapur). This project is funded by Government of Switzerland and Government of Nepal under Nepal Agricultural Services Development Programme (NASDP). Evidences in the first phase show that with the availability of a year-round irrigation, yield of these crops increase by more than 30 percent. In addition, the cropping intensity increased by more than 40 percent resulting in an overall productivity increase by more than 50 percent. SIP Phase II will be the continuation of SIP Phase I. SIP-II will be implemented by Local Governments (LGs) as the mandate to implement small irrigation programs lies with rural municipalities and municipalities of Province 1.

2.1.7 Community irrigation project (CIP)

The Community Irrigation Project (CIP) is developing small-scale irrigation systems in 12 districts in Nepal through a community-driven process targeted to poor, women and other disadvantaged groups. The participating districts were selected based on high poverty, food insecurity and irrigation potential, and include Kanchanpur, Kailali, Dang, Kapilvastu in the Terai plains, Doti, Salyan, Rukum, Rolpa, Pyuthan in the hills, and Bajhang, Jumla, Mugu in the mountains. Community Irrigation Project (CIP) was approved by ADB on 27 September 2010 and grant became effective on 5 May 2011. It was targeted to be closed on 15 July 2018 however; construction of some irrigation infrastructure project is going on. The project is funded by ADB, Government of Nepal (GoN) and beneficiaries. CIP had the overall goal of increasing agriculture income of rural poor and socially disadvantage groups. To achieve this objective CIP aims to develop irrigation infrastructure covering 13,000 ha of agricultural land of small surface FMIS (having command area less than 25 ha in the hills and mountains and 200 ha in the Terai) and development of 4,000 ha of shallow tubewell (STW) groundwater irrigation systems with 40 ha cluster area. Sub-projects were planned to be implemented in four batches of which 1st batch consists of 50 sub-projects, 2nd batch of 160 subprojects, 3rd batch of 108 subprojects and 4th batch of 104 subprojects.

Up to now from all CIP projects, there are 50 irrigation sub project (ISP) of 1,639 ha command are under Batch-1, 127 ISP of 3,995 ha under Batch-2, 171 ISP of 5,140 ha under Batch-3, 93 ISP of 4,1434 ha under Batch-4. The number and command area of completed and ongoing CIP projects in the FtF district (Terai) are provided in **Table 2-2** and a list of all constructed and under construction CIP irrigation project given in Annex 2-1 (b) and Annex 2-1 (c) respectively

Table 2-2: Number of CIP projects and total command areas (ha) within the Feed the Future Zone of Influence districts (Terai only) (Source: CIP, 2020)

District	Number of completed projects	Command area of completed projects (ha)	Number of ongoing projects	Command area of ongoing projects (ha)
Kapilbastu	24	2575.9	5	486.4
Dang	31	2744.3	0	0.0
Kailali	52	2414.2	5	550.0
Kanchanpur	31	1877.1	1	40.0

2.1.8 Local infrastructure for livelihood improvement (LILI)

Local Infrastructure for Livelihood Improvement (LILI) is an SDC/Helvetas initiative. The Phase I of the programme started in August 2006 for a period of 3 years in 6 Swiss and Helvetas cluster districts namely Doti, Achham, Jajarkot and Dailekh in the west, and Dolakha and Ramechhap in the east. The program was implemented with the objective of increasing the level of income and food security of the remote and food deficit hill areas through supports in small to medium sized farmer managed irrigation systems. Following successful outcome from the Phase I activities, a decision was taken to design and implement LILI Phase-II from the second half of 2009 across Nepal.

2.2 Status of irrigation development

Status of existing, under construction and planned irrigation projects in the FtF-ZoI districts (Terai only) is synthesized/analysed primarily based on irrigation water use inventory database prepared along with Irrigation Master Plan (IMP, 2019). **Table 2-3** summarizes various aspects of irrigation development in the FtF-ZoI districts (Terai only). Nepal has 2.265 Million ha of land suitable for irrigation, about 65% (or 1.594 Million ha) of that area lies in Terai region of Nepal. About 310,260 ha of land within the FtF-ZoI districts (Terai only) have irrigation facility, which varies across the FtF-ZoI districts as shown in **Table 2-3**.

Table 2-3: Key features of irrigation systems within Feed the Future Zone of Influence region, western Nepal (Sources: IMP, 2019 GIS database; IMP, 2018)

District	Total area under irrigation (ha)	Surface irrigation system					GW irrigation system						
		GCA (Ha)	NCA (Ha)	No. of irrigation system	No. of AMIS	No. of LIS	Total GCA under GW irrigation (ha)	Deep tube well (DTW)		Shallow tube well (STW)		Area under DTW (%)	Area under STW (%)
								No. of wells	GCA (ha)	No. of wells	GCA (ha)		
Kapilbastu	28,826	24,023	15,915	24	1	3	4,803	85	1,825	2,978	2,978	38	62
Dang	37,911	31,322	27,548	119	0	0	6,589	119	2,565	4,024	4,024	39	61
Banke	48,461	39,457	25,076	30	1	4	9,004	82	2,565	6,439	6,439	28	72
Bardia	72,718	62,978	34,921	14	2	0	9,740	35	1,080	8,660	8,660	11	89
Kailali	76,614	45,195	29,554	23	1	0	31,419	75	2,315	10,799	29,104	7	93
Kanchanpur	45,733	21,485	16,874	21	1	0	24,248	58	2,200	8,039	22,048	9	91
Total	**310,264**	**224,461**	**149,890**	**231**	**6**	**7**	**85,803**	**454**	**12,550**	**40,939**	**73,253**	**15**	**85**

Notes: No. is Number; AMIS is Agency Managed Irrigation System; LIS is lift irrigation system; GCA is gross command area; NCA is net command area; ha is hectares; GW is groundwater; Data on STW and DTW are based on records until Fiscal Year 2073/74 (or until July, 2017). The command areas provided in the Table are the government reported planned for command area but not the actually served area and does not include private investments (e.g. in groundwater). Major irrigation projects in Kapilbastu is Banganga; Banke is Sikta; Bardia are Babai and Rajapur; Kailali is Ranijamara and Kanchapur is Mahakali. Tubewells with depth < 50m are considered as STWs.

2.2.1 Surface water irrigation schemes

As per the inventory report compiled by Irrigation Master Plan (IMP, 2019), there are 231 surface irrigation schemes in operation within FtF-ZoI districts (Terai only) (please refer **Annex 2-1** for details of those schemes), covering a total gross and net irrigation command areas[3] of 224,461 ha and 149,890 ha, respectively (**Table 2-3**). This statistic includes all Farmer Managed Irrigation System (FMIS), Agency Managed Irrigation System (AMIS) and Agency-Farmer Managed Irrigation System (AFMIS). Distribution of irrigation command areas and location of headworks of those irrigation schemes across the FtF-ZoI districts are shown in **Figure 2-1**. Most of the irrigation schemes are FMISs, with gross command areas ranging from 12 ha to 6,000 ha. Besides FMISs, there are six large-scale irrigation schemes in the FtF-ZoI districts (Terai only) managed by the federal and provincial governments. Department of Water Resources and Irrigation (DWRI, formerly known as Department of Irrigation) at Federal level manages Sikta (GCA = 42,766 ha) in Banke; Babai (GCA = 35,421 ha) and Rajapur (GCA = 17,140 ha) in Bardia; Rani Jamara Kuleria (GCA = 24,516 ha) in Kailali; and Mahakali (GCA = 14,020 ha) in Kanchapur. Government of Lumbini Province

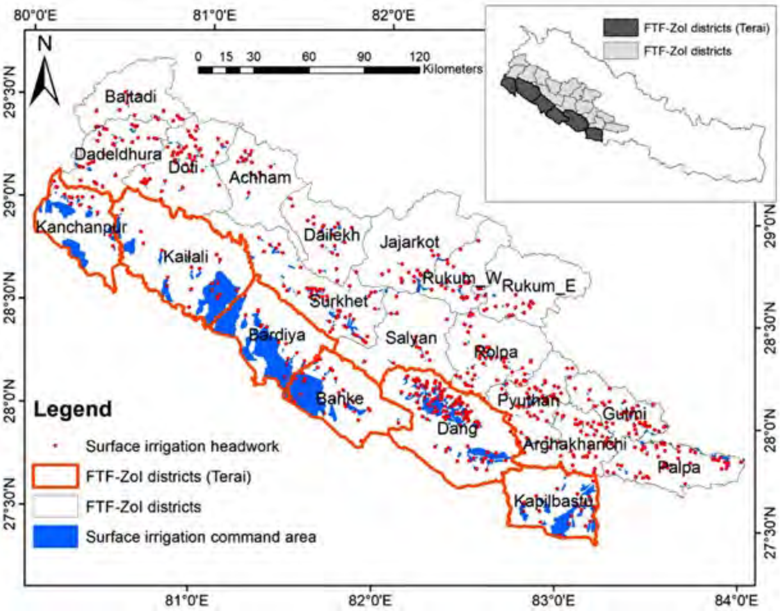


Figure 2-1: Distribution of existing surface irrigation projects (command areas and headwork) within the Feed the Future Zone of Influence districts (Source: prepared based on database from IMP, 2019).

[3] Gross command area is the total area which can be economically irrigated from an irrigation scheme without considering the limitations of water (i.e., GCA = culturable command area (CCA) – uncultivated areas). Net command area is the total area that are actually irrigated by an irrigation system (i.e., NCA = CCA – the area occupied by canals, canal network and ditches)

is responsible for the management of the sixth large irrigation scheme, namely Banganga (GCA = 10,734 ha) in Kapilvastu. Additionally, there are seven lift irrigation schemes within the FtF-ZoI districts (Terai only), out of which, four (4) are in Banke and three (3) in Kapilbastu districts (**Table 2-3**), management responsibility of which are attributed to the provincial government. Their key features are provided in **Annex 2-1**.

i) Under-construction surface water irrigation projects

There are at least five under-construction surface water irrigation projects within the FtF-ZoI districts (Terai only) (IMP, 2019) as summarized hereunder;

- **Mahakali-3 Irrigation Project:** A Treaty for the Integrated Development of Mahakali River including Sharada, Tanakpur, and Pancheswor Multipurpose Project was signed between Nepal and India on 12 February 1996. The water entitlement to Nepal is comprised of two offtakes. First one, which is under construction, is from Tanakpur Barrage with design discharge of 28.35 m^3/s during wet season and of 8.5 m^3/s during dry season. They are designed to irrigate a total of 28,255 ha of land with an estimated costing of NPR 26.78 Billion. Second intake at Sharada barrage has been drawing upon water for many years to irrigate 11,600 ha of land in Kanchanpur district under Mahakali.
- **Sikta Irrigation Project**: This is one of the national-pride projects declared by the government of Nepal in 2007 AD. A 317 m high barrage has been built across the West Rapti River, for diverting water. It's designed to irrigate 33,766 ha on right bank and 9,000 ha on left bank of the river. The construction of 45 km western main canal has been completed while construction of 53 km eastern main canal is underway. The capacity of each canal is 50 m^3/s. This system will benefit from the Naumure multipurpose project (MPP). With estimated cost of NPR 25 billion, this is one of the largest irrigation project in the country. The intended completion date for the project was 2015 AD, but it has not been completed yet (Investopaper, 2020). A significant portion of the construction work is already completed. Once this project is completed, 42,766 ha of arable land is designed to have irrigation facility (Belt & Road News, 2020).
- **Rani-Jamara-Kulariya Irrigation Project:** This project currently extracts water from the Karnali river through a free intake. The project is designed to extend to about 57,320 ha of land. The estimated cost of the project is NPRs 27.7 billion and aims to irrigate 38,300 hectares of arable land round the year. The government has set a target to complete this project by fiscal year 2023/24. Along with the activities of rebuilding farmer-managed canals, developing mechanisms to protect the irrigated areas and improving the village agriculture road, the main purpose of this project is to increase the production and productivity of not only the main irrigated crops, but also vegetables and fruits, by introducing improved technologies and practices as well as better use of irrigation water (Belt & Road News, 2020).
- **Mega Dang Valley Irrigation Project:** This project is designed to irrigate 56,000 ha, of which 37,000 ha from the Naumure MPP by storage and diversion, 4,000 ha from lift irrigation, and 4,000 from local storage. It's targeted to be completed by 2044. Jade Consult (2019) studied the feasibility of dams in Dang valley to impound water for irrigation. The Dang valley, located in Dang district, is one of the largest valleys of the country. The Dang valley, has potential irrigable area of about 60,000 ha including Deukhuri valley and Tulsi-Dang. The proper Dang valley has total irrigable area of about 43,000 ha, part of which is being irrigated from seasonal streams and rivers. The year-round irrigation coverage in the valley is limited to small proportion of the area commanded by several FMISs and deep tube wells.
- **Bheri-Babai Diversion Multipurpose Project (BBDMP):** The project is designed to divert water from the Bheri river to Babai river via a transfer tunnel (12.2 km length and design flow of 40 m3/s) (**Annex 2-2a**), for irrigating about 51,000 ha in Banke and Bardiya districts (including the Babai and Dhodhari irrigation schemes), with the options of diversion structure and hydropower generation (46 MW). Out of 51,000 ha of designed irrigation coverage, nearly 42,500 ha already have irrigation facility and the rest would be developed as new irrigation command areas. As per water availability, there would be no deficit of water after implementation of this project. The project is expected to be completed by 2024. The construction of 12.2-kilometers-long tunnel using Tunnel Boring Machine (TBM) for the first time in Nepal, a major component of the national pride project, was completed in April 2020, a year before the expected completion time and within the allocated budget (Belt & Road News, 2020).

ii) Planned surface water irrigation projects

As indicated in **Table 2-3**, nearly 30% of irrigable land still do not have access to irrigation. Having realized the importance of year-round irrigation (YRI), the Government of Nepal (GoN), as per IMP (2019) is planning to implement multipurpose inter-basin water transfer project (IBWTP), diverting water from water surplus river to water deficit ones. Out of 11 inter-basin water transfer projects identified in Nepal, six (actually six scenarios with four projects) are located within the FtF-ZoI districts. The IBWTPs are generally of large scale in terms of potential irrigated areas, infrastructure and costs, and also in most cases include hydropower generation, and therefore also referred to as multipurpose projects. Maximum irrigable areas for IBWTPs are limited by water availability in donor catchment. **Table 2-4** summarizes key features of the six IBWTPs located within the FtF-ZoI area. The estimates of surface water availability for irrigation in **Table 2-4** for irrigation are based on river basin modelling using MIKE HYDRO Basin.

Table 2-4: Potential areas under irrigation and maximum irrigable areas limited by water availability in the six water-transfer projects in the Feed the Future Zone of Influence districts, Western Nepal. (Source: IMP, 2019)

Irrigation Project	Potential Total Area for Irrigation (ha)	Max Irrigable Area (ha) based on Water Availability			Max discharge in tunnel (m^3/s)	Reservoir
		Total	Existing	New		
1. Bheri-Babai Diversion Multipurpose Project	45,111	45,111	42,467	2,644	64.4	No
1.1 Beri-Babai Transfer only	*45,111*	*45,111*			*64.4*	*No*
1.2 Beri-Babai Transfer + Nalsyauga Dam	*45,111*	*45,111*			*64.4*	*Nalsyauga Dam*
1.3 Beri-Babai Transfer + Uttar Ganga Dam	*45,111*	*45,111*			*64.4*	*UttarGanga Dam*
2. Karnali Transfer to Kailali Irrigation	40,628	40,628	7,632	32,996	58.6	No
3. Madi Dang Diversion	35,639	17,107			24.2	Madi Dam
4. Naumure Dam (Rapti Kapilbastu) Diversion	86,874 [*57,142 ha in Kapilbastu; 29,732 ha in Sikta*]	40,849	15,226	25,632	74.9	Naumure Dam

Notes: Potential area ha means the potential irrigation command area by the project, Max irrigable area based on water availability means the water available for irrigation. From Naumure dam, only 40,849 ha will go to Kapilbastu and remainder to Sikta Irrigation Project.

Among four project, Madi Dang Diversion and Namure Dam Projects show deficiency of irrigation water, with each can irrigate only 48% and 59% of potential irrigable areas. However, feasibility study is being conducted for economical and adequate location of project so as to supply required irrigation water demand. A brief overview of the projects is provided hereunder;

- **Bheri-Babai Diversion Multipurpose Project (BBDMP):** The BBDMP (please refer **Annex 2-2a** for layout) has three variants – (i) transfer tunnel only; ii) transfer tunnel plus Nalsyaugad dam; and (iii) transfer tunnel plus Uttar Ganga. The first variant (i.e., transfer tunnel only) is under construction and remaining variants are planned to implement in subsequent years. This project diverts only part of the flow, which would be available for nearly 100% of time in the river, thus assuring design discharge and power production practically throughout the year. Thus, in terms of utilization of water resources, this is one of the most attractive multi-purpose projects in Nepal. The GoN has considered it as the Project of National Pride (BBDMP, 2020).
- **Karnali Diversion Project:** The project would divert water from the Karnali River to the Terai via a 19 km tunnel (design flow 59 m3/s) to supply an irrigated area of about 41,000 ha, of which 33,000 ha would be new irrigated lands (**Annex 2-2b**). The project also includes a hydropower plant of nearly 80 MW installed capacity. This system would infill the irrigable land between the end of the Mahakali-3 irrigation project in the west, and the command area of Rani Jamara Kuleria Irrigation Project, which extends from the east in Kailali. The Karnali Diversion Project extracts from the free intake on the Karnali river at Chisapani. This is the preferred option to irrigate these lands in preference to the Karnali-Chisapani High Dam. The high dam would inundate 360 km^2 of land and provide 10.8 GW of power. The issue of inundation and associated social and environmental impacts are likely to delay this project, whereas the diversion project could take place much quicker with cheaper and has much lesser social and environmental impacts. This projected is expected to be completed in long-term, by mid-2040s.
- **Madi Dang Diversion Project:** The proposed development is for the diversion of water from the Madi River to the Dang valley via a 25 km tunnel (design flow of 24 m^3/s) with a dam across the Madi River and production of hydropower (61 MW) (**Annex 2-2c**). It would supply sufficient water to irrigate about 17,100 ha, of which a significant proportion would be used for existing irrigation systems. This project was initially identified as uneconomical; however, it is under review with alternative location of dam and alternative tunnel.
- **Naumure Dam (Rapti-Kapilbastu Diversion) Project:** The project would divert water from the Madi River to the Terai to irrigate about 40,849 ha (out of 51,000 ha available for irrigation). Irrigation would be supplied to about 25,600 ha of new command area and about 15,200 ha of existing command areas (in Kapilbastu district). The infrastructure includes: Naumure storage dam (169 m high), regulation dam (13 m high), hydropower station (approx. 100 MW installed capacity), and transfer tunnels (21 km long) (**Annex 2-2d**). This project is found as economically viable and is recommended in the shortlist of the plan. It is being studied by DoED and will be available for detailed design soon. This projected is expected to be completed in long-term (i.e., 2030-2040).

iii) Planned lift irrigation projects

Some of the issues and concerns of hill irrigation are low irrigation coverage, less area covered by YRI, low level of water use efficiency, and underutilization of developed infrastructures. Those concerns are mainly driven by inadequate water resources available in small and medium rivers. Run off river diversions without storage facility and southern rivers originating from Chure hills have low flow in winter and spring and could not cope with irrigation water requirement. Moreover, due to technical, and financial limitations with rugged topography, it is difficult for river diversion or storage works in lower and mid hills. Therefore, lift irrigation systems by pumping water from river courses running parallel to agricultural fields are considered as a better option.

Solar is being considered as potential source of energy in some of the planned lift irrigation projects in the FtF-ZoI districts in Western Nepal. The advantage of solar power is the low running costs, as it usually runs when sunlight is available. The limitation is variation in power generation across the hours in the day depending upon solar intensity, which may alter water supply to irrigation farms. Following are the solar-lift irrigation systems planned in the region as per IMP (2019).

- Bheri Corridor Irrigation Development Project: The project covers the river corridor length of about 125 km along the Bheri River (**Annex 2-2e**). The project has identified 195 lift irrigation systems; 149 are planned to operate by solar power, and remaining 46 by electrical power. These projects aim to provide water to the community using small lift pumps without distribution systems.
- Bheri Ghatgau-II Irrigation Project: This project (**Annex 2-2f**) has a command area is 87 ha, lift head of 67 m and design discharge of 27 l/s. The pump size of 15 kW with two units are required to meet duty. The solar panels are located on the bank of the river.
- Kusetara Irrigation Project: This project lifts water and distributes to 1.5 ha area using multiple outlets through a low-pressure alfalfa valves (**Annex 2-2g**). The unit cost is $3,000/ha as this includes distribution system as well as larger size (i.e., 160 mm diameter) pipes and valves.
- Integrated Energy and Irrigation Special Program: This program initiated by DWRI is under implementation in the major river corridors through the country. The program is expected to be the largest solar lift projects in near future.

2.2.2 Groundwater irrigation schemes

Groundwater irrigation status within the FtF-ZoI districts (Terai only) is synthesized based on irrigation water use inventory report (IMP, 2018). The report documents government-funded tubewell constructions, but does not include privately installed tubewells that have grown rapidly. Therefore, the numbers reported in the report underestimate the true extent of groundwater irrigation in the Terai. As per the inventory report (IMP, 2018), There are about 40,939 STWs and 454 DTWs within the FtF-ZoI districts (Terai only), providing irrigation water to 73,253 ha and 12,550 ha, respectively (**Table 2-3**). Some of the notable groundwater irrigation projects initiated by the government include Community Grounwater Irrigation Project, Community Shallow Tubewell Irrigation Project, Bhairahawa Lumbini Groundwater Irrigation Project, Nepal Irrigation Sector Project, etc. Most of STWs are designed with a capacity of 1 ha of irrigated land per STW. Groundwater irrigation systems are supplying irrigation water to about 28% of total irrigated land, with variation across the FtF-ZoI districts (Terai only) from 13% (in Bardia) to 53% (in Kanchanpur). The districts in decreasing order of gross command area (GCA) under groundwater irrigation are Kanchanpur (53%), Kailali (41%), Banke (19%), Dang (17%), Kapilbastu (17%) and Bardiya (13%). Out of total areas irrigated by groundwater, almost 85% are supplying water from STW and rest from the DTW. Contribution of STW in total groundwater irrigation varies across the districts, from 61% in Dang to 93% in Kailali (**Table 2-3**).

There is no specific information on **planned irrigation projects** in published literatures. One of the important government's initiative in this regard that is under implementation is the Sambriddha Terai Madhesh Irrigation Special Program. However, IMP (2019) illustrates the planned groundwater irrigation areas based on the deficit water from surface irrigation project across the districts. The idea is the deficit irrigation area which is not sufficient from surface water will be covered by groundwater. Results tabulated in **Table 2-5** indicate that there is no deficit water for Bardia and Kanchapur districts, therefore, no future groundwater irrigation is planned for those two districts. However, it's uncertain that whether all available surface water can be diverted for irrigating farmlands and even if yes, how many years will it take and whether they can meet irrigation demands at the time crop needs. Under such circumstances, investments for groundwater irrigation also needs to be prioritized in those areas as well.

Kapilbastu and Dang districts need more priority of planned groundwater development to fulfil the irrigation shortage from surface irrigation system. As areas under groundwater irrigation in Kapilbastu and Dang districts are only few hundred hectares and by the end of planning period more areas may need groundwater supply either due to decrease in efficiency of surface water systems as well as more areas coming under irrigation, and/or increasing demands of other water use sectors, it's proposed to plan groundwater irrigation for all the areas tabulated in column-7 in **Table 2-5**. As per IMP (2019), groundwater irrigation project in Kapilbastu (command area = 33,000 ha) is expected to be completed in mid-term (i.e., 2025-2029) whereas groundwater irrigation projects in Dang (command area = 28,000 ha), Banke (command area = 18,000 ha) and Kailali (command area = 4,000 ha) are expected to be completed in long-term (i.e., 2030-2040).

Table 2-5: Potential areas for groundwater development across the Feed the Future Zone of Influence districts (Terai only).

District	Project Scenario	Total area suitable for irrigation (Net, ha)	Areas irrigated from existing irrigation projects (Net, ha)	Remaining areas to be irrigated (ha)	Areas that can be irrigated with available surface water (ha)	Areas to be irrigated with groundwater (ha)
Kapilbastu	Naumure Dam, Transfer	90,505	24,322	63,013	33,714	33,000
Dang	Madi Dang Transfer MPP+Naumure	77,729	32,474	32,552	17,541	28,000
Banke	Naumure Dam, Transfer	57,564	39,823	17,741	0	18,000
Bardia	Bheri-Babai Transfer	64,551	63,002	1,549	45,111	0
Kailali	Karnali Transfer	90,288	45,980	44,308	40,628	4,000
Kanchanpur	Mahakali-3	56,649	18,317	38,332	38,332	0

2.3 State of knowledge generation

There are several literatures, both scientific and grey, that document varying aspects of knowledge on water resources and water infrastructure development in the Western Nepal in general, and FtF-ZoI districts in particular. At least 53 literature link water resources, irrigation and agriculture development within the FtF-ZoI districts. Their references, main focus, data/information that they offer, and key findings are synthesized in **Annex 2-3**.

Most of the scientific literature are related to water availability assessment (e.g., Pandey et al., 2019; 2020; Dahal et al., 2020), flood forecasting and early warning systems, inundation modelling and flood risk assessment, prioritizing river basins for flood risk management (DWRI/WRPPF, 2020a, b, c), etc. Literature related to water availability assessment have provided information on current as well as projected future water balance (in climate change context) in most of the river basins in the Western Nepal. Some literature (e.g., DOA, 2018) also elaborated strength, weakness, opportunities and threat regarding agriculture development and conclude that Lumbini Province (Terai FtF districts – Banke, Bardia, Dang, Kapilbastu) has a large fertile land, suitable for all kinds of cereals crops but having low YRI facility as a key challenge. Similarly, Sudurpaschim Province that has Kailali and Kanchanpur as FtF-ZoI districts in Terai ha both Hills and Terai with presence of many donor-funded projects. However, agriculture development in this Province is yet to realize the full potential due to lack of market infrastructure for value chain development as well as issues with year-round irrigation access.

Similarly, studies like IWMI (2019) have focused on generating integrated knowledgebase on the basins in the Western Nepal (mainly, Karnali, Mohana and Mahakali river basins) by characterizing biophysical aspects, institution-policy landscape, environmental aspects (by estimating environmental flows requirements), mainstreaming gender and social inclusion (GESI), and trade-offs and synergies among potential future development pathways. The study revealed that the annual surface water availability is generally sufficient to meet existing and growing demands in energy and agricultural sectors. However, their large spatio-temporal variations suggest the need for water storage and/or strategies such as planned CU to ensure that the available water is accessible to where and when needed.

Despite having a large number of sporadic literatures both grey and scientific, focusing on various aspects of knowledgebase in the region, there are very limited studies focusing on agriculture, irrigation, and planned conjunctive use (CU) in the FtF-ZoI. Furthermore, available studies have used different types of approaches and methods and carried out at different scales. However, no studies have been carried out focusing on the generation of integrated knowledgebase on various aspects of water resources, water infrastructure development, conjunctive use, and sustainable use and management of both the resources.

2.4 Data/Information gaps

There is quite a good amount of information on water development initiatives in the FTF-ZoI districts (primarily in the Terai), in terms of water development programs/projects, status of irrigation projects, and state of knowledge generation. However, following gaps in data/information still exists;

- Geospatial data for surface irrigation systems are available only for those with command areas greater than 10 ha and 25 ha in hill and Terai, respectively. Details of irrigation systems below the aforementioned thresholds are not considered in this report, primarily due to data/ information gap.
- Groundwater irrigation command area is mentioned in literature, but CU of surface water and groundwater across the FtF-ZoI districts are not reported anywhere. Therefore, current status of CU, limitations, and learnings is a gap in literature.
- Geospatial data on irrigation command areas and headwork of surface irrigation schemes are well documented, however, no such documentation is available for groundwater irrigation systems. Therefore, there is a gap on availability of groundwater abstraction points, their command area, and other relevant information specific to groundwater command areas.
- Potential groundwater irrigation schemes identified by IMP (2019) are based only on surface water deficit for unirrigated land. However, actually planned groundwater irrigation projects, and associated details are not available in literature, either due to non-existence of such planned projects or due to no documentation of such.
- The Literature provide information on gross and net command areas under surface irrigation system. However, performance of those systems in technical and economic terms, both surface and groundwater, their current status, and potential to expand command area with year-round-irrigation (YRI) is missing in the literature. This is still an active area for research/study.
- There are almost no studies that consider withdrawal patterns of water for agricultural uses and the maintenance of environmental flows.

3. Water Availability

3.1 Surface water availability

Present and future surface water availability in the river basins in the FtF-ZoI are reviewed based on published literature and then tabulated and elaborated in the following sub-sections. There are five major river systems that cover the three provinces (i.e., Lumbini, Karnali, and Sudurpaschim) (**Figure 3-1**) in the FtF-ZoI. They, from west to east, are Mahakali, Mohana, Karnali, Babai, and West Rapti. In addition, there are some part of Narayani River Basin and some southern rivers too, which are seasonal in nature and originate in Chure/Mahabhart range of Nepal Himalaya. The Karnali is the largest river system, with total drainage area (up to the border with India) of 45,954 km^2. This river system is further sub-divided into following sub-basins, West Seti, Bheri, Tila, Humla Karnali and Mugu Karnali. Irrigation Master Plan 2019 (IMP, 2019) has divided the entire country into three main river basins for the purpose of hydrological modeling. As per the report, all five river systems in the FtF-ZoI will fall under Karnali basin. In addition, there are also Southern rivers that originate in Chure/Mahabhart range. They are seasonal in nature, however, are also important source of water in rainy season.

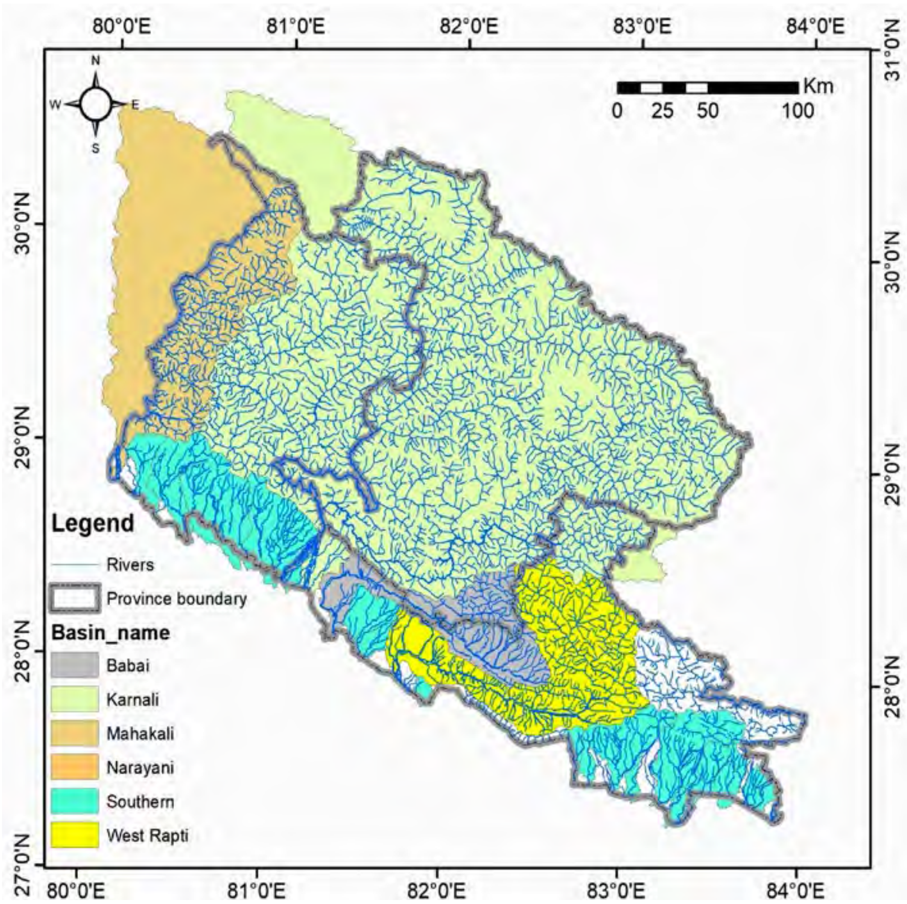


Figure 3-1: Major river systems in Feed the Future Zone of Influence region

i) Chamelia: The Mahakali basin, as delineated at a point below the Nepal-India border in the Digo Jal Bikas Project, covers 17,377 km^2 (Pandey et al., 2019). Mahakali is a transboundary basin with about two-thirds of the basin falling in India and the rest in Nepal. The Mahakali river forms the border between India and Nepal and then joins Ganges basin in India. Chamelia is the largest watershed in the Nepalese side of the Mahakali Basin, covering an area of 1,603 km^2. The average annual runoff of Mahakali River contributed by tributaries in Nepal-side is about 7,789 MCM and that of Chamelia is 2,081 MCM. A model-based study by Pandey et al. (2019) using SWAT model indicated that average annual streamflow is projected to increase gradually from the near to far future under both RCPs; for instance, by 8.2% in near (2021-2045), 12.2% in mid (2046-2070), and 15.0% in far future (2071-2099) under RCP4.5 scenarios. The projected increasing trend is consistent across all the seasons. However, the increase in streamflow is greater in winter (DJF), and then for pre-monsoon (MAM), post-monsoon (ON), and then to monsoon (JJAS) seasons.

ii) Mohana: The Mohana river that borders between Kailali and Kanchanpur districts originates in Churia hills of Nepal, descends through the Terai, and drains into Karnali River at the Nepal-India border. The watershed area of Mohana above the Nepal-India border is 3,730 km^2. Mohana comprises of parallel stream network characterized by flash floods in the monsoon (Pandey et al., 2020a). Average annual rainfall in the Mohana watershed is about 2,010 mm, actual evapotranspiration is about 37% of average annual rainfall and river discharge at the outlet of the Mohana is 152 m^3/s (Tripathee, 2018). Projected future average annual water availability in the Mohana basin is estimated as 16% (24%), 4% (14%) and 17% (18%) for the near, mid and far futures under RCP 4.5 (RCP 8.5) scenarios. But the change in the stream flow varies throughout the month. Discharge is projected to increase in dry and pre monsoon season by about 30% under RCP 4.5 and by 50% under RCP 8.5.

iii) Karnali: It is a transboundary, snow-fed and perennial river system with Karnali as the main river of the system. The Karnali river originates from the Tibetan Plateau near Lake Mansarobar at an elevation of 4800 m and Mapchachungo Glacier and flows towards the south and joins the Sarada River at Brahmaghat in India. After joining to Sarada, together they form Ghagara River, a major left bank tributary of the Ganges. Out of 45,954 km^2 drainage area of the Karnali River Basin (above Nepal-India border), 3,109 km^2 lies in Tibet (Dhami et al., 2018). The river spans 230 km from the northern basin boundary to the Chisapani station in the south. There are several studies that estimates surface water availability in the Karnali river basin, however, the estimates vary considerably as indicated in **Table 4-1** due primarily to taking different boundaries and basin areas. As per Pandey et al. (2020), out of the 1,375 mm of rainfall in the Karnali river basin, 34% is lost as evapotranspiration (AET) but with a large spatio-temporal variability. The AET in the Trans-Himalayas, Mountains, Hills and Indo-Gangetic Plain (IGP) regions are 26%, 37%, 36% and 35%, respectively (Pandey et al., 2020). Total annual volume of water available in the Karnali river basin is estimated in the range of 43,173 – 44,673 Million-Cubic-Meters (MCM) **(Table 3-1)**. The discharge is projected to increase by 0.6 % in near future (2021–2045), by 6.4 % in mid future (2046–2070), by 8.4% in far future (2071-2099) under RCP 4.5. And by 9% in NF, 5% in mid future, 10.9% in FF under RCP 8.5 scenarios.

Major tributaries of the Karnali river are Bheri, West Seti, Tila, and Upper Karnali. Bheri river system drains from the catchment area of 12,290 km^2. The elevation of the basin varies from 200 to 7746 meters above mean sea level (masl) with permanent snow-capped mountains such as the western Dhaulagiri range in the north. Bheri River is about 264 km long, flows nearby Surkhet, and joins the Karnali River within the Mahabharata range at about 15 Km upstream from Chisapani. Three main tributaries of the Bheri are Sani Bheri, Thuli Bheri and Uttar Ganga. Average annual discharge at Jammu hydrological station located near to the confluence with the Karnali river is 361 m3/s (Pandey et al., 2020), which translates into an average annual volume of 11,383 MCM. Water resources under RCP4.5 scenarios are projected change by -5.4% in NF and +3.0% in MF. Under RCP8.5 scenarios, it is projected to decrease by 2.5 % and 1.3 % for NF and MF, respectively **(Table 3-1)**.

The West Seti (area = 7,460 km^2) is another important tributary of the Karnali river that originates from the glaciers and snowfields around the twin peaks of Nampa and Api in the main Himalayas, facing towards the South. As with most of the Himalayan basins in Nepal, the West Seti has large elevation, ranging from 610 masl to 7,019 masl. A major part of this area (about 63.26%) is forest, with 28.17% agricultural land (Bhatta et al., 2020). The West Seti contributes average annual discharge of 283.6 m3/s (or flow volume of 8,944 MCM/yr), which under RCP4.5 scenarios is projected to increase from 13.9 % in NF to 16.1 % in FF. In case of RCP8.5 scenarios, it is projected to increase from 14.5 % in NF to 16.0 % in MF **(Table 3-1)**. The flow volumes in the Seti river is projected to increase across all the months, albeit with varying rates; higher increase in winter, pre-monsoon and post-monsoon seasons and lower during the monsoon season.

The Tila (area = 1,870 km^2) is another sub-basin of the Karnali river basin that contributes 1,470 MCM volume of water annually in the Karnali river. Projected changes in future climate is expected to decrease water availability by 21.6 % (19.5%) in NF and 13.4 % (13.2%) in FF under RCP 4.5 (RCP 8.5) **(Table 3-1)**. Tila also shows projected decrease in precipitation and increase in actual evapotranspiration.

In addition, the Upper Karnali river system defined as the basin area above Lalighat hydrological station (index = Q215) gets inflows from two major tributaries of Karnali, namely, Humla Karnali and Mugu Karnali. It has a total basin area of 15,200 km2 and contributes a total of 8,993 MCM volume of water per annum in the Karnali river. Water availability in the Upper Karnali, under RCP4.5 scenarios is projected to change by -7.3 % in NF and 2.3 % in MF. Under the RCP8.5 scenarios, the projected changes are -7.2 % in NF and -5.8 in FF. Flow volumes are projected to decrease during monsoon season and increase during winter and pre monsoon season; albeit with varying rates.

iv) Babai: It originates from a low mountain in Siwalik and flows north-westward parallel with Bheri river then southward passing through Royal Bardia National Park. It joins the Karnali river at about 50 km downstream from Nepal-India border. Two studies have reported water availability in the range of 2,800 MCM (considering watershed above Nepal-India border) to 4,248 MCM (considering watershed at confluence with the Karnali river basin at downstream of the Nepal-India border). In terms of projected future surface water availability, there are no such studies published so far. Bhattarai et al. (2019) prepared and inundation map of a section of Babai Basin (40km south of Babai Bridge in Ratna Rajmarga), assessed impacts of inundation under different return periods, and concluded that a large percentage (47 to 49%) of area vulnerable to loss/damage from inundation is agricultural land, followed by water body (38 to 46%) and forest (3 to 10%).

v) West Rapti: The West Rapti river originates from the Mahabharat range of Nepal, it enters the lowlands and finally drains to Ghagra (Karnali) river, a tributary of Ganges River in India. Jhimruk River, Mari River, Arun River, Lungri River, Sit River, Dunduwa River, Sotiya and Gandheli rivulets are the main tributaries. The river is named West Rapti River at the downstream of confluence of Jhimruk and Mari rivers (Shrestha, 2017). The West Rapti beholds immense importance concerning its significance in water supply for agriculture, irrigation, and domestic usage to the West Terai region of Nepal. The length of main stream channel is 257 km and average slope of the river system as per Talchabhadel et al. (2019) is 16.8%. The average rainfall for West Rapti Basin is about 1,500 mm. Reported water availability in the West Rapti basin is in the range of 3,200 MCM/yr to 7,064 MCM/yr **(Table 3-1)**. And increment of annual mean discharge between baseline and future period range from 2.6 m^3/s to 8.1 m^3/s for RCP 4.5 and from 8.8 m^3/s to 44.8 m^3/s for RCP 8.5 scenarios. Flooding and associated economic impact on agriculture and household is reported as high in the West Rapti basin, especially in future periods and lower parts due to projected increase in flood frequencies and intensities (Perera et al., 2015).

vi)Southern Rivers: In addition to these large and medium river systems, there are a large number of small rivers in the Terai which mostly originate in the Siwalik Range. Flow in these rivers is mostly dependent on monsoon precipitation, and their flow level could deplete significantly during the non-monsoon period (Shrestha et al, 2018). These rivers are seasonal with little flow during the dry season, which renders them unsuitable for year round irrigation or hydropower generation without surface storage. It is observed that around 78% of the average flow of the country is available in the large river basins, 9 % in the medium basins and 13 % in the numerous small southern rivers of the Terai (WECS, 2011). Specifically studies on the southern river of Western Nepal is not available.

3.2 Groundwater availability

Terai and Inner Terai regions of Nepal are considered rich in groundwater resources (Pathak, 2018). There are six Terai and six hill districts in the FtF-ZoI (**Figure 1-1**). All Terai districts have flat topography except Dang, which is the Dun valley in inner Terai. Groundwater is the most important source of water in Terai region due to its readily availability and good quality. Groundwater resources in the Terai are underdeveloped. It estimates that about 88% of the groundwater that could be abstracted on a sustainable basis is not utilized, providing ample space for increased groundwater use for productivity enhancing irrigation (Urfels et al., 2020). Sustainable utilization and management of groundwater resources require a thorough understanding of aquifer systems, their hydrogeologic characteristics, and availability as well as spatio-temporal distribution of groundwater resources in the FtF-ZoI.

This study identified, screened and reviewed available literature to characterize groundwater availability in the FtF_ZoI in western Terai. Literature were identified by searching google and google scholar with following keywords: groundwater, aquifer characteristics, aquifer property, western Terai groundwater, Terai Nepal, Kanchanpur, Dang, Bardia, Banke, Kailali, Kapilbastu, aquifer system, hydrogeology, groundwater storage, groundwater availability, Karnali, mahakali, Babai, West Rapti, Mohana, and groundwater quality. This process identified 21 studies. After reading title and abstract and then scanning through the contents, eight (8) literature were excluded from detailed review as they were more focused on details of geological formation in Dang, Siwalik and Indo-Gangetic regions. Furthermore, some literature that were focused on other regions rather than FtF-ZoI were also excluded from further review. Finally, remaining 13 studies were reviewed in detail with specific focus on groundwater availability, recharge, aquifer (hydrogeological) characteristics, tubewell depth, aquifer yield, and groundwater quality. Two more literature related to groundwater quality, which were focused on very small areas were also excluded as they may not add value in understanding groundwater of the entire FtF-ZoI. Finally, groundwater availability was characterized based on detailed review of 11 remaining studies.

3.2.1 Groundwater aquifers

There are basically two types of aquifer systems in Nepal's Terai, namely, shallow aquifer (0-46 m depth) and deep aquifer (> 46 m deep), as defined by GDC (1994). A schematic of the aquifer system in Nepal's Terai is shown in **Figure 3-2**, and that in mid-western and western regions, in which FtF-ZoI is located, are shows in **Figure 3-3**. Though a detailed characterization of aquifer system and their hydrogeologic properties are not well documented, there are sporadic studies that discusses those features. For example, Transmissivities of both shallow and deep aquifers in all the six Terai districts of FtF-ZoI are provided in **Table 3-3**. Similarly, hydrogeological characteristics of aquifer systems in Dang valley is reported in Sapkota (2003) **(Table 3-4)**.

Table 3-1: Surface water availability in the river systems in the Feed the Future Zone of Influence

S.N.	Basin name [Outlet]	Basin area (km^2)	Baseline period	Baseline discharge (m^3/s)	Baseline water availability (MCM/yr)	Change in water availability in future time period	References
1	Chamelia [Confluence with Mahakali]	1,603	2001-2013	66.0	2,081	NF (2021-2045): +8.2% (RCP4.5); MF (2046-2070): +12.2% (RCP4.5); FF (2071-2099): +15.0% (RCP4.5)	Pandey et al. (2019)
2	Mahakali [Outlet]	5,410	-	247 (from Nepal)	7,789	No data available	WECS (2011)
3	Mohana [Confluence with Karnali]	2,918	1980-2005	152	4,793	NF (2018-2040): 16% (RCP4.5), 24% (RCP8.5); MF (2041-2070): 4% (RCP4.5), 14% (RCP8.5); FF (2071-2099): 17% (RCP4.5), 18% (RCP8.5)	Tripathee (2018)
4	Karnali [Chisapani]	42,890	1995-2009	1,414.3	44,602	NF (2021-2045): 0.6% (RCP4.5), 9% (RCP8.5); MF (2046-2070): 6.4% (RCP4.5), 4.2 (RCP8.5); FF (2071-2095): 8.4% (RCP4.5), 10.9% (RCP8.5)	Pandey et al. (2020)
5	Karnali [Chisapani hydrological station]	42,457	1981-2005	1,375	43,362	MF (2040-2069): 6.4% (5.1%) for RCP4.5 (RCP8.5); FF (2070-2099): 8.4% (10.9%) for RCP4.5 (RCP8.5)	Dahal et al. (2020)
6	Karnali [near Chisapani hydrological station]	42,845	1985-2005	1,480	46,673	No data available	Dhami et al. (2020)
7	Karnali [Chisapani]	45,269	1981-2010	1,369	43,173	No data available	Khatiwada (2016)
8	Karnali [above confluence with the Ganges in India]	63,700	-	1,900	60,000 (approx.)	No data available	IMP (2019)
9	Karnali-Mohana [Nepal-India border]	49,892	1995-2009	1,467	46,250	No data available	Pandey et al. (2020)
10	Bheri [Jammu Hydrological Station]	12,290	1995-2009	361	11,383	NF (2021-2045): -5.4% (RCP4.5), -2.5 (RCP8.5); MF (2046-2070): +3.0% (RCP4.5), +1.3 (RCP8.5); FF (2071-2095): -0.5% (RCP4.5), -3.1% (RCP8.5)	Pandey et al. (2020)
11	Bheri [Jammu hydrological station]	13,900	1975-2005	415	13,087	NF (2020-2044): +7.1% (RCP4.5), +6.0% (RCP8.5); MF (2045-2069): +6.2% (RCP4.5), +7.2% (RCP8.5); FF (2070-2099): +7.3% (RCP4.5), +12.5 (RCP8.5)	Mishra et al. (2019)
12	West Seti [above Bangna Hydrological station]	7,460	1995-2009	283.6	8,944	NF (2021-2045): +13.9% (RCP4.5), +14.5 (RCP8.5); MF (2046-2070): +13.8% (RCP4.5), +16.0 (RCP8.5); FF (2071-2095): +16.1% (RCP4.5), +13.2% (RCP8.5)	Pandey et al. (2020)
13	West Seti [above Ghopaghat Hydrological station]	4,324	1996-2005	-	-	NF (2020-2044): +16.4%; MF (2045-2069): +18.3%; FF (2070-2099): +19.9% (all projections are under RCP8.5 scenarios)	Bhatta et al. (2020)
14	Tila [above Nagma hydrological station]	1,870	1995-2009	46.6	1,470	NF (2021-2045): -21.6% (RCP4.5), -19.5% (RCP8.5); MF (2046-2070): -1.2% (RCP4.5), -17.2 (RCP8.5); FF (2071-2095): -13.4% (RCP4.5), -13.2% (RCP8.5)	Pandey et al. (2020)
15	Upper Karnali [above Lalighat hydrological station	15,200	1995-2009	285.2	8,993	NF (2021-2045): -7.3% (RCP4.5), -7.2% (RCP8.5); MF (2046-2070): +2.3% (RCP4.5), -0.3% (RCP8.5); FF (2071-2095): -1.0% (RCP4.5), -5.8% (RCP8.5)	Pandey et al. (2020)
16	Babai [above Nepal-India border]	3,000	-	88.8	2,800	No data available	Pandey et al. (2010)
17	WECS [above the confluence with Karnali river at about 50 km downstream of border]	3,400	-	103	3,248	No data available	WECS (2011)
18	West Rapti [above Nepal-India border]	3,380	until 2010	101.5	3,200	No data available	Pandey et al. (2010)
19	West Rapti [above Jalkundi hydro-station]	-	1982-2005	-	-	FF (2071-2100): Increment range from .6 m^3/s to 8.1 m^3/s for RCP 4.5 and from 8.8 m^3/s to 44.8 m^3/s for RCP 8.5.	Shrestha (2017)
20	West Rapti [above the confluence with Karnali river at downstream of Nepal-India border]	6,500	Until 2003	224	7,064	No data available	WECS (2003)

Notes: NF is near future, MF is mid-future, FF is far-future, RCP is representative concentration pathway; MCM is million-cubic-meters.

Table 3-2: Key hydrologic features of the river basins/sub-basins in the Feed the Future Zone of Influence

River basin/ sub-basin in the Western Nepal	Catchment area (km^2)	Average annual rainfall (mm)	Average annual discharge (m^3/s)	Average discharge of monsoon season (JJAS, m^3/s)	Specific discharge ($l/s/m^2$)	Average annual flow volume (MCM)	Runoff (mm)	Runoff coefficient (-)	Average annual evaporation (mm)	Reference
Karnali	42,845	1,481	1,480	3,057	34.5	46,673	1,089	0.74	374	Dhami et al. (2018)
Bheri	12,290	1,202	361	766	29.4	11,383	926	0.77	n/a	Pandey et al. (2020, b)
Seti	7,460	1,921	284	623	38.0	8,944	1,199	0.62	n/a	Pandey et al. (2020, b)
Tila	1,870	n/a	47	88	24.9	1,470	786	n/a	n/a	Pandey et al. (2020, b)
Upper Karnali (above Lalighat hydrological station)	15,200	n/a	285	580	18.8	8,993	592	n/a	n/a	Pandey et al. (2020, b)
Mohana	2,918	2,010	152	n/a	52.1	4,793	1,642	0.82	747	Tripathee (2018)
Chamelia	1,603	2,469	66	983	41.2	2,081	1,298	0.53	381	Pandey et al. (2019)
West Rapti	3,380	1,500	101	n/a	29.9	3,200	947	0.63	n/a	Pandey et al. (2010)
Babai	3,000		98	n/a	32.7	2,800	33	n/a	n/a	Pandey et al. (2010)

Notes: n/a is not available; mm is millimeters; JJAS is June-July-August-September; MCM is million-cubic-meters.

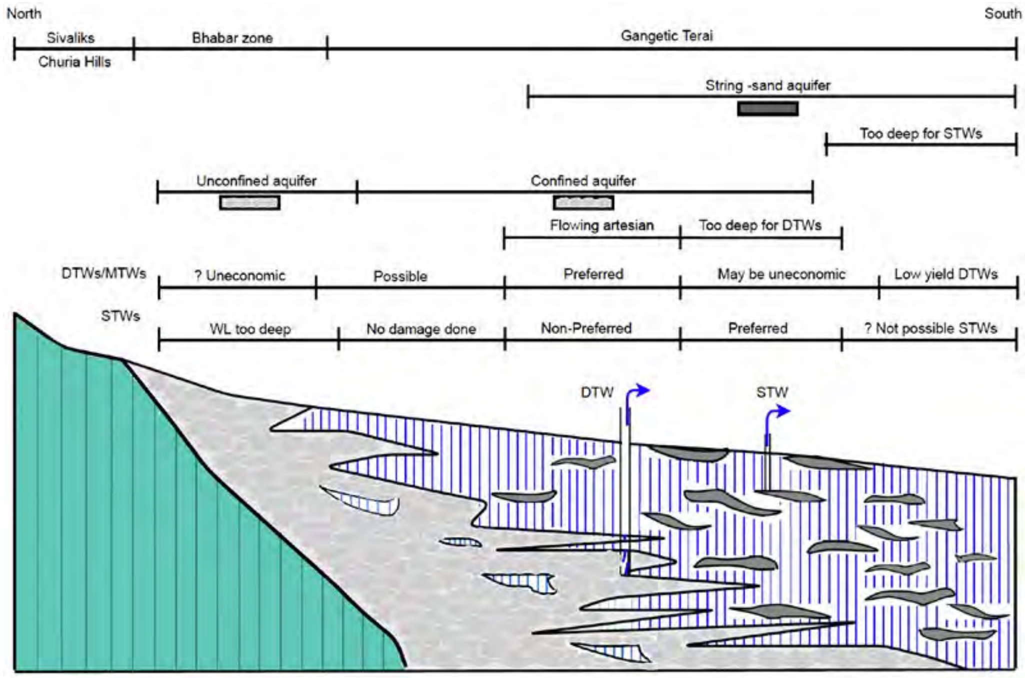


Figure 3-2: Schematic section through main terai aquifers in Nepal (Adapted from: GDC, 1994). STW is shallow tube well; WL is water level; DTW is deep tubewell;.

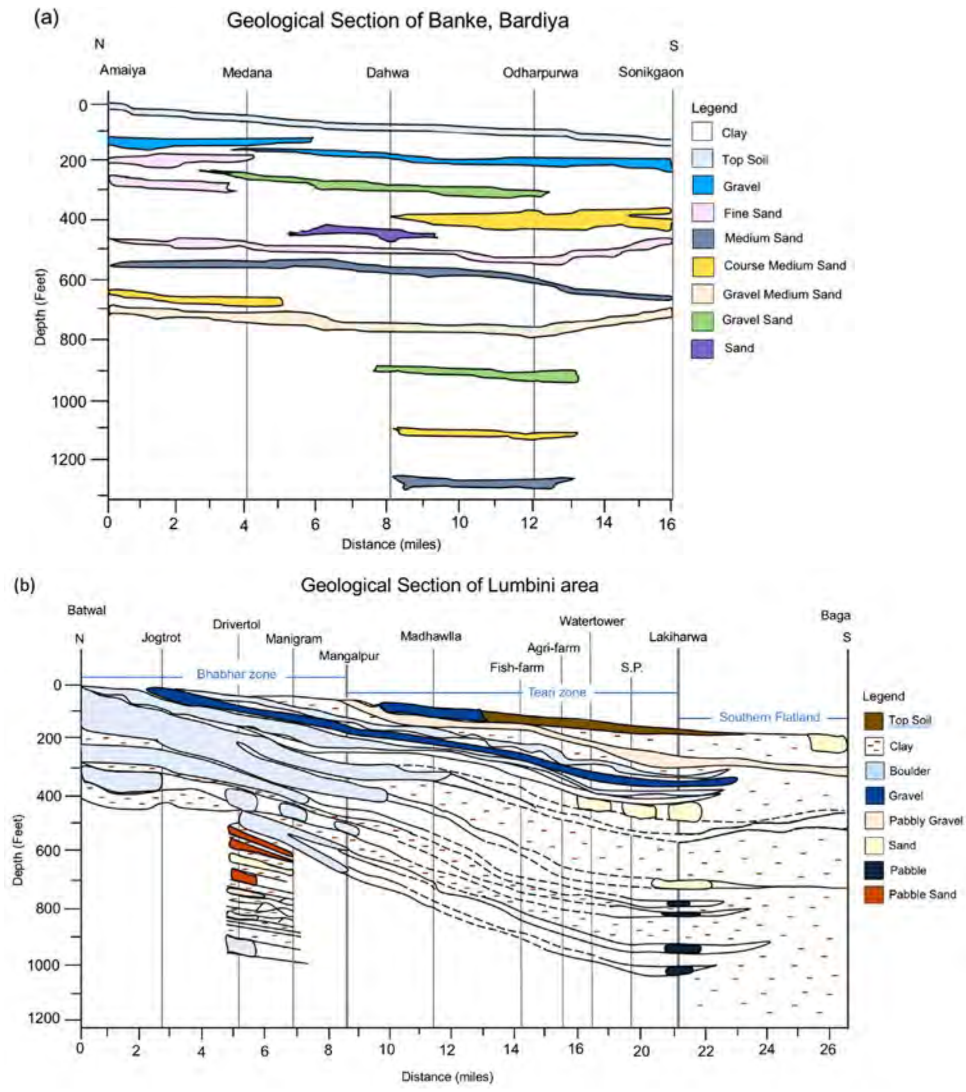


Figure 3-3: Geological cross-section of – a) mid-western, and b) western (Lumbini area) regions of Nepal (Source: Sharma, 1974)

Table 3-3: Hydrogeologic characteristics of groundwater aquifers in the Feed the Future Zone of Influence (Source: GDC, 1994)

District	Transmissivity, m^2/day	
	Shallow Aquifer (0-46 m depth)	Deep Aquifer (> 46 m depth)
Kapilbastu	513	300 – 1,000
Dang	18-5,670	1,035 – 5,670
Banke	-	470-3,050
Bardia	380-550	180-510
Kailali	Very low	30-2,892
Kanchanpur	Very low	80-2,495

Notes: Depth boundary for shallow and deep aquifers are as defined in GDC (1994) for Nepal's Terai

Table 3-4: Hydrogeological characteristics of deep and shallow aquifers in Dang measured in sample observation wells (Source: GWRDB, 1996)

Well No.	Water Level (masl)	Depth of well (m)	Total cumulative thickness of aquifer (m)	Piezometric surface (m bgl)	Discharge/ maximum yield (m^3/day)	Transmissivity (m^2/day)	Hydraulic conductivity (m/day)
DG/DTW-6	632.0	70.1	9.18	15.8	1483.5	3394.0	369.7
TG-5	608.0	107.0	30.0	21.0	691.2	632.5	21.1
DG/DTW-9	633.0	113.5	37.2	6.0	-	-	-
DG/DTW-21	618.0	74.4	16.5	37.5	-	-	-
DG/DTW-7	580.0	111.2	21.4	-	630.0	-	-
DG/DTW-3	583.0	106.1	-	11.0	-	-	-
DG/STW-7	638.0	20.1	7.1	3.2	950.4	3477.5	-
DG/DTW-5	610.0	140.0	22.0	9.2	167.1	101.9	4.6
NISP/STW-7	636.0	36.0	6.1	0.7	661.8	712.5	117.3
DG/STW-6	580.0	37.5	6.1	5.0	1987.2	-	-
DG/DTW-27	586.0	111.2	33.9	5.1	2592.0	3953.0	116.4
DG/DTW-1	619.0	149.4	11.0	15.2	194.4	14.2	1.3
DG/DTW-2	641.0	68.9	11.1	23.7	-	-	-
Saibahini	666.0	29.0	-	-	0.1	-	-
TG-2	604.0	105.0	30.4	28.9	1036.2	2709.3	89.1

Notes: masl is meters above mean sea level; mbgl is meters below ground level

3.2.2 Groundwater resources

Renewable groundwater resources in Terai are the result of recharge from the northern edge of the Terai, the Bhabar Zone, along the Siwalik foothills (Shrestha et al., 2018) as indicated in **Figure 3-2**. Groundwater in Terai's aquifers is recharged from direct infiltration of rainfall as well as lateral recharge from Bhabar zone. Sub-surface inflow and seepage losses through the streams and rivers also provide significant input to the groundwater recharge. Clear delineation of groundwater recharge areas for groundwater system in Nepal's Terai is yet to made.

Distribution of renewable groundwater availability across the districts in the FtF-ZoI as per IMP (2019), based on estimates of groundwater recharge using SWAT model, is shown in **Table 3-5**. The estimates also includes relative contribution from three zones, namely, Bhabar, seepage, and Terai (please refer **Figure 3-4** for zones). Using per km^2 availability of renewable groundwater resources as an indicator, districts in decreasing order of groundwater availability are Kanchanpur, Kapilbastu, Bardia, Banke, Kailali, and Dang.

Table 3-5: Renewable groundwater resources across Terai districts in the Feed the Future Zone of Influence (Source: updated with data from IMP, 2019). Districts are listed from East to West.

District	District area (km^2)	Net groundwater recharge (MCM/yr)				Renewable groundwater availability (MCM/km^2/yr)
		Bhabar Zone	Seepage Zone	Terai Zone	Total	
Kapilbastu	1656	280	175	237	692	0.42
Dang	3015	130	9	185	324	0.11
Banke	1891	320	167	145	632	0.33
Bardiya	2014	211	185	363	759	0.38
Kailali	3312	522	73	269	864	0.26
Kanchanpur	1633	320	135	334	789	0.48

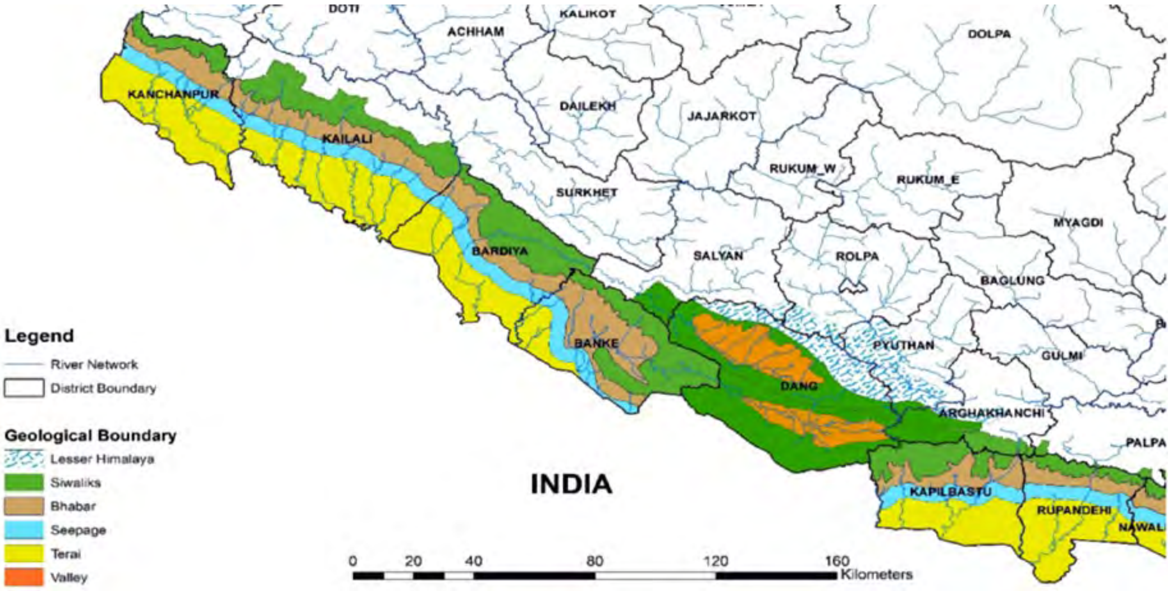


Figure 3-4: Conceptual model of geology and model Zones for Western region of Nepal Terai (Source: IMP, 2019)

Besides IMP (2019), there are very few literature that provide information on groundwater and aquifer characteristics. Pathak (2018) evaluated present situation of the existing groundwater exploitation in the entire Terai and Inner Terai and reported status of deep wells in each district in terms of number of wells, average depth of tube well, and yield (litres per second, lps). Most deep tubewells are drilled in Kailali and then in Kapilbastu and the Bardia has comparatively less number of deep tubewells (**Table 3-6**). It is observed that the deep wells in Dang have been exploiting the deepest aquifers (~ 300 m deep) for better quality and quantity of groundwater, while the wells in other districts exploit aquifers from relatively shallower depths. Well yield is high in Bardia district (32 lps), followed by Kanchanpur (28 lps) and Dang has relatively lower yield (only 15 lps). Good correlation between the well depth and average well yield indicate the deeper wells have higher possibility to tap multi-aquifers and the permeable confined aquifer and therefore have more yield compared to shallower ones. Wells between 50 and 75 m deep have the lowest yield while it gradually increases for the wells between 175 and 200 m deep.

Table 3-6: Characteristics of deep wells and water level depth in aquifers in Terai districts in the Feed the Future Zone of Influence (Source: modified from Pathak (2018) and Shrestha et al. (2018))

District	Deep wells			WL in deep aquifer (mbgl)		WL in shallow aquifer (mbgl)	
	# of wells	Avg. depth of well (m)	Well yield (lps)	Max	Min	Max	Min
Kapilbastu	110	180	20	5.0	0.1	5.0	0.0
Dang	75	300	15	23.0	4.0	16.5	0.0
Banke	85	190	-	14.0	1.0	6.0	0.0
Bardiya	25	160	32	12.0	9.0	10.0	0.2
Kailali	160	195	21	-	-	7.0	1.2
Kanchanpur	70	140	28	-	-	5.0	1.0

Notes: WL is water level; Avg. is average; m is meters; mbgl is meters below ground level; Max is maximum; Min is minimum; lps is liters per second.

There are other studies which focuses on specific areas within the FtF-ZoI. For example, WECS (2011) estimated that groundwater availability in shallow aquifer alone in Dang is about 130-140 MCM/yr. Similarly, Sapkota (2003) studied on hydrogeological conditions in the southern part of Dang valley and provided hydrogeological characteristics. The study also estimated safe yield from the groundwater aquifers in the southern part of Dang valley as 3.16 x 10^7 m^3 /year, whereas groundwater abstraction for domestic use alone is estimated as 7.43 x10^6 m^3 /year, thus indicating stress on groundwater system. After including abstraction for irrigation, actual volume of groundwater abstraction would be much higher. This indicates the need for proper planning and management for sustainable utilization and management of groundwater resources in the FtF-ZoI.

3.2.3 Groundwater quality

Groundwater is a significant water source for drinking and irrigation. However, groundwater is extremely prone to contamination from constituents such as Arsenic, Iron, and microbial pathogens from natural and mostly from anthropogenic sources. These contaminations can cause significant harm to human health and crop quality. Arsenic contamination is one of the main concern in deep groundwater as most of the published articles on water quality have studied on groundwater arsenic contamination and associated impacts. Long-term use of arsenic contaminated groundwater for irrigation may result in increase of arsenic concentration in the agricultural soil and eventually arsenic accumulation in plants (Bhattacharya et al., 2009). FAO guideline recommend concentration limits for irrigation water like Arsenics, Iron, fluoride, sodium. For instance, Arsenic concentration for irrigation water should not exceed 100 ppb (FAO, 1985) and that for drinking water should not exceed10 ppb (WHO, 2020). Therefore, understanding of state of groundwater quality and drivers of groundwater contamination are necessary to establish sustainable groundwater use.

There are limited study that characterize groundwater quality in the entire FtF-ZoI. Most of the studies related to groundwater quality are concentrated in Kailai district and then in Kanchapur district. Shrestha et al. (2018) reports concentration of arsenic (**Table 3-7**) as well as that of other water quality parameters (**Table 3-8**) across the Terai districts of FtF-ZoI. About 20% of deep tube well of Kailali and Bardia district has arsenic concentration above 10 ppb and 4-15% of tube wells have arsenic concentrations above 10 ppb in other five district. Maximum percent of arsenic concentration above 50 ppb found in 11% of Tubewell (TW) of Kailali district among Terai FTF district.

Yadav et al (2012) analysed vulnerability of Arsenic contamination in six Terai districts in Nepal, including Kailali and Kanchanpur in FtF-ZoI. Out of the six study districts, the highest mean Arsenic concentration (6.27 mg/l) was observed in Kailali district followed by Kanchanpur (4.98 mg/l). There is a gradual increase in Arsenic level in shallow tubewells up to a depth of 50m, which then tends to decrease at depths below 70m. It indicates that abstracting groundwater from deeper depths may help avoid Arsenci intake in groundwater use. Mahat and Shrestha (2008) assessed arsenic and metal contaminations in groundwater of Dang district. Analysis of a total of 523 water samples from tubewells and dugwells revealed that 50.3% and 10.7% of tube/dug-wells contain arsenic above WHO guideline value (i. e., 10 ppb) and Nepal Standard (i.e., 50 ppb) for drinking water, respectively. Arsenic concentration up to 240 ppb was found in Dhikpur in Dang district. Groundwater in this area are affected by high concentration (up to 11 mg/l) of iron and of manganese (up to 0.51 mg/l).

Table 3-7: District-wise arsenic concentration in Terai districts in the Feed the Future Zone of Influence (Source: Shrestha et al., 2018)

District	% of Tubewells with Arsenic concentration (parts per billion, ppb) of			
	0–10	11–50	> 50	> 10
Kapilbastu	88.5	7.6	3.9	11.5
Dang	95.4	4.6	0.0	4.6
Banke	88.7	10.0	1.3	11.3
Bardiya	77.9	18.4	3.7	22.1
Kailali	67.1	21.6	11.3	32.9
Kanchanpur	85.3	9.6	5.1	14.7

Table 3-8: Concentration of different chemical constituents in groundwater mostly from shallow aquifer across the Feed the Future Zone of Influence. (Source: Shrestha et al., 2018)

Parameter	Unit	Banke	Bardiya	Kailali	Kanchanpur	Nepal drinking water standard*
pH	-	6.2– 7.3	6–7.5	6–7.17	5.5–6.92	6.5–8.5
Ammonia	mg/ L	<0.01-0.38	<0.01-0.37	<0.01-0.648	0.112– 1.688	1.5
Iron	mg/ L	0.04– 2.96	0.03– 2.21	0.03– 3.39	<0.001-0.38	0.3
Total hardness	mg/ L	149.5– 383	181.8– 686.6	113.1– 363.6	99.58– 419.08	500
Electric conductivity	μs/ cm	420– 1540	300– 900	150– 640	210–710	1500
Total alkalinity	mg/ L	77.4– 324.2	154.4– 347.4	81.06– 393	125–341	n/a
Chloride	mg/ L	12.8– 134.6	10.9– 112	9.62– 64.1	5.128– 41.024	250
Nitrate	mg/ L	<0.1-0.5	<0.1-0.5	<0.1-0.5	<0.001-2.15	50
Phosphate	mg/ L	n/a	n/a	0.6–3	n/a	n/a
Sulfate	mg/ L	1–71	1–75	1–26	0–31	250
Sodium	mg/ L	6.6– 84.7	4.3– 118.2	2.73– 39.6	0.425– 60.72	n/a
Potassium	mg/ L	0.4– 5.9	1.8–3.7	1.2– 4.2	0.345–7.59	n/a
Total dissolved solids	mg/ L	273– 1001	195– 611	n/a	n/a	1000

* Agricultural standards may differ from drinking water standard, however, specific information on agricultural water standards are not yet available.

Bohara (2015) studied physiochemical and microbiological quality of various groundwater sources i.e. hand pumps and taps for domestic purpose in Bhim Datta Municipality of Kanchanpur district. The data obtained from physico-chemical analysis of water samples were within both the national standard and WHO guideline. However, arsenic total hardness, total alkalinity, ammonia, Chloride, Nitrate were not in satisfactory level. Hand pump/tube well water was more contaminated than piped/tap water supply often contamination of Iron. However, many households have to resort to hand pumps because of poor reliability and services of piped water. The drinking water quality was poor in both chemical and biological parameters.

Gurung et al. (2015) assessed drinking water quality parameters (biophysical-chemical) from groundwater sources in Bhajani and Chuha areas of Kailali district. Analysis of 24 groundwater samples revealed that the parameters such as colour, pH, turbidity, TDS, EC and total hardness are within the prescribed limit by National Standard for drinking water quality. Some heavy metals such as Al, Pb, Cd, Fe, As and Mn exceeded in some of the samples indicating possible risk to the community. Water quality standards for agricultural use are yet to develop for the region, however, they are expected to be different than those for drinking.

3.3 Data/Information gaps

- For some of the basins such as West Rapti and Babai, all water balance components and their spatio-temporal distribution for historical period are missing due to absence of comprehensive hydrological modelling. Furthermore, projected future climate and associated impacts on water availability is missing in those watersheds.
- Though a broad level of information is available, spatio-temporal distribution of groundwater resources (storage, recharge) across different locations and depths in aquifers are not adequately documented in literature.
- Estimates of sustainable yield from the aquifers at different locations and depths are missing in literature
- Most of the studies related to groundwater quality, with relatively large sample size, are conducted in Kailali, Kanchanpur and Dang districts. Similar studies are required for other districts in the FtF-ZoI as well to adequately characterize spatial distribution of groundwater quality in the FtF-ZoI region.
- Understanding recharge process, its dynamics, and prospects for enhancing recharge to ensure sustained availability of groundwater for CU is as important as understanding current availability of groundwater resources. It requires information on seasonal fluctuations on groundwater tables, long-term trends in groundwater tables, potential areas for groundwater recharge, and identification and evaluation of potential interventions for enhancing recharge and protecting sources (e.g., springs in case of mid-hills), which of course, are site specific. Such information, though highly valuable, are not documented in literature most likely due to lack of such studies in the study region in particular, and in Nepal in general.

4. Water Demand

Understanding of water demands and its spatio-temporal distribution is another important parameter required for designing systems for conjunctive use of both surface and groundwater resources. Locating water demand hot-spots, assessing water availability in those areas, and exploring viable sources of water in the water demand hot-spots are imperative to design and implement conjunctive water use systems.

This study identified, screened and reviewed literature that estimate various types of water demands in the FtF-ZoI. Literatures were searched from google and google scholar using following key words: water demand, western Nepal, water use, irrigation water demand and use, domestic water demand and use, Karnali, Mahakai, West Rapti, Babi, Mohana, Kapilbastu, Dang, Banke, Bardia, Kailali, Kanchanpur. Furthermore, various websites (e.g., Central Bureau of Statistics, CBS, Nepal) were also visited to search for irrigation-related data. The list of studies identified were screened first by reading abstract and introduction. The literature that have quantitative data on domestic and/or irrigation water demand and irrigation-related data like source of drinking water, irrigation water, cropping intensity, agricultural land, agricultural production, irrigation land area were screened for detailed review. This process resulted a selection of 17 studies. After reading through the text of these studies, six (6) were excluded as they did not have adequate information on water demands. Finally, 11 studies were included for detailed review that have contents such as domestic and/or irrigation water use/demand, and/or have data (e.g., cropping pattern, cropping intensity, irrigation command area, agriculture areas, etc.) that are useful to estimate water demands.

Crucially, our literature review indicated that there is no comprehensive study report on estimates of water demands within the FtF-ZoI. Some studies that have estimated approximate values of domestic and irrigation water demands are scattered across different locations, but none cover the entire areas of FtF-ZoI. For example, Pandey et al. (2010) reported basin-wise irrigation and domestic water demands. The study concludes that Babai has maximum percentage of water use (77.2% of available water resource); Mahakali has minimum water use (2.6 %) (**Table 4-1**); the Babai needs to have proper water management; while the Mahakali and Karnali can be considered as the areas with large potentials for new water development projects. Key highlights from these studies are presented below.

Table 4-1: Estimated water use/demand and associated statistics in the river basins within the Feed the Future Zone of Influence (Source: Pandey et al., 2010).

River basin	Irrigation use (MCM)	Domestic use (MCM)	Total use (MCM)	Water use (% of WR)	Agricultural area (%)	Irrigation area (%)
Mahakali	450.96	26.49	477.45	2.64	23.26	29.86
Karnali	2,983.31	62.44	3,045.75	6.91	5.91	37.63
Babai	2,144.45	17.03	2,161.48	77.20	19.96	51.08
West Rapti	353.20	20.81	374.01	11.69	44.13	30.78

The Water Resources Strategy (2002) states Babai as a water deficit basin, however, after diversion of water from Bheri is realized soon after completion of ongoing project, it becomes water-surplus. Similarly, The Mahakali and West Rapti are considered as basins with adequate water whereas Karnali is considered as water surplus basin that offers opportunities for later multi-purpose projects.

Pandey et al. (2012) assessed water poverty of medium-sized river basins in Nepal using water poverty index (WPI)[4] as a framework and concluded that West Rapti and Babai within the FtF-ZoI have higher water poverty compared to other basins in Nepal. Similarly, Panthi et al. (2018) analysed WPI in Humla, Kalikot and Kailali districts and concluded that Kalikot has the highest water poverty followed by Humla district and water poverty is the lowest in Kailali district. Water poverty is estimated as low in Terai districts due to irrigation potential, however, there are risks of extreme events such as floods.

Pakhtigian et al. (2019) calculated irrigation and municipal water demands within Karnali, Mohana and Mahakali River basins for economic benefits analysis. Irrigable areas were calculated by differencing crop water requirements (using CROPWAT and CLIMWT tool) and effective rainfall. 60% of irrigation efficiency was taken as average of conveyance and application irrigation efficiency. Cropping pattern and cultivable land areas were specified based on district-specific data from the MoALD (2014). Crop yields were then determined based on historical agricultural productivity and constrained to avoid water shortage in the most water-constrained months of the growing period. Municipal water demand was estimated using

[4] WPI is an interdisciplinary tool to assess water stress by linking physical estimates of water availability with socio-economic drivers of poverty.

population-based approach of 2011 census data. A daily per capita water requirement was assumed to be 45 litres based on survey. This value varies from rural to semi-urban to urban areas in the range of 45-135 litres per capita per day (lpcd). According to households' survey 10 % of domestic water needs come from surface water sources and other 90% for domestic needs come from groundwater, specifically from tubewells.

Another study from Pathak (2018) has published a map with location of deep tubewells (DTWs) across Terai districts in Nepal (**Figure 4-1**). The map indicates potential irrigation hot-spots to get an idea for targeting conjunctive use of surface and groundwater systems.

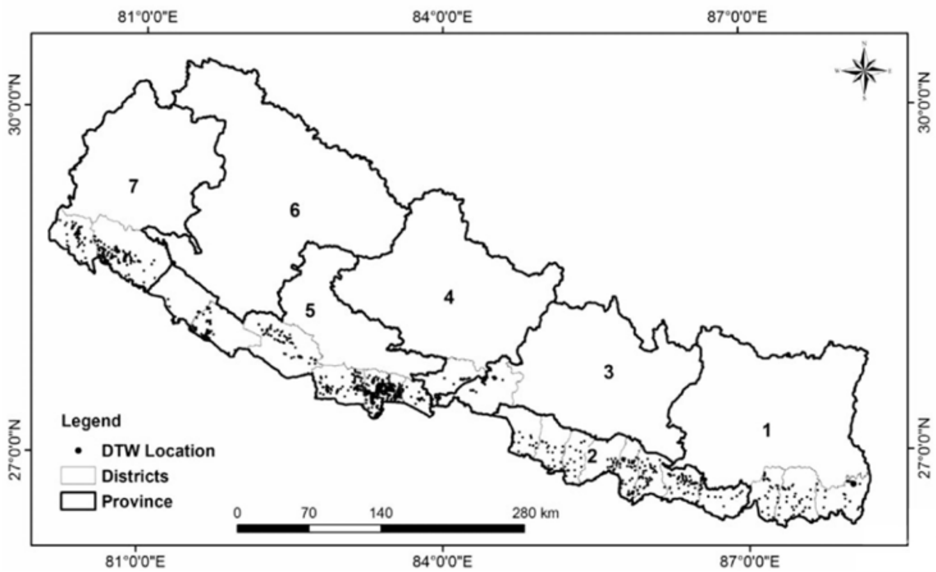


Figure 4-1: Location map of the deep tubewell distribution in study districts (Source: Pathak, 2018)

Furthermore, district profiles published by the Ministry of Agriculture and Livestock Development has provided some useful information for estimating irrigation water demands in three Terai districts within FtF-ZoI area as indicated in **Table 4-2**. And, finally, very recently, Irrigation Master Plan (IMP, 2019) and other sources also provide relevant information for estimating irrigation water demand. They are provided in **Table 4-3**.

Table 4-2: Agriculture and irrigation-related indicators in selected districts within the Feed the Future Zone of Influence (Source: District profile published by Ministry of Agriculture and Livestock Development)

Indicator	Dang district	Banke district	Kailali district
Proportion of population in agriculture-related occupation (%)	Agriculture (20.7%); salaried/wage agriculture (3.0%)	Agriculture (35.4%); salaried/wage agriculture (3.0%)	Agriculture (23.8%); salaried/wage agriculture (3.4%)
Major sources of drinking water	Piped water (67.8%), open well (13.3%), and hand pump/tube well (8.3%)	Hand pump/ tube well (93.1%), piped water (6.6%)	Hand pump/ tube well (85.1%), piped water (12.4%)
Major sources of irrigation	Continuous flow canal (63.9% for irrigated agriculture land, 78.1% for temporary crops), tube well/boring (13.9% for irrigated agriculture land, and 5.3% for temporary crops)	Others (47.1% for irrigated agriculture land, 37.0% for temporary crops); continuous flow canal (25.1% for irrigated agriculture land, 20.7% for temporary crops), tube well/boring (17.9% for irrigated agriculture land, 16.3% for temporary crops)	Continuous flow canal (37.6% for irrigated agriculture land, 24.7% for temporary crops), tube well/boring (36.0% for irrigated agriculture land, and 50.6% for temporary crops)
Major cropping patterns in Khet land	Rice-Wheat-Fallow (31.6%); Rice-Wheat-Maize (23.0%); Rice-Maize-Fallow (13.0%); Rice-Rice-Wheat (12.2%)	Rice-Wheat-Fallow (48.9%); Rice-Fallow-Fallow (14.6%); Rice-Wheat-Maize (9.7%)	Rice-Wheat-Fallow (39.1%); Others (38.2%); Rice-Fallow-Fallow (7.5%)
Major cropping patterns in Bari land	Maize-Tori-Fallow (86.4%)	Others (63.5%); Maize-Rice-Wheat (9.0%); Maize-Tori-Fallow (7.5%)	Vegetable-Vegetable (49.2%); Others (31.8%); Vegetable-Maize (13.2%)

Table 4-3: Supporting data for estimating irrigation water demand (Source: various, as indicated inside the Table itself)

Source	Name of Report/ Information	Description of information	Limitation/Gap
Central Bureau of Statistics (CBS, 2011)	National Sample Census of Agriculture 2011/12.	In Province 5, Source of irrigation is 22% by gravity, 13% by pumping, 27% by dam/reservoir, 33% by tubewell/boring, 3% by others and 1% by mixed. In Province 7, source of irrigation is 52% by gravity, 5% by pumping, 12% by dam/reservoir, 28% tubewell/boring, 2% of others and 1% by mixed source of irrigation.	Didn't find in the context of district but it has been stated by some report.
Ministry of Agricultural and Livestock Development.	District profile of Dang, Banke, Kailali district based on baseline survey of 2015.	District wise agriculture occupation, source of drinking water, irrigation water, cropping pattern of in Khet land and Bari land.	Only available for three Terai FtF district.
	Frequently asked question on agriculture	Few information can be found related to crop irrigation system like for Rice, 2-3 cm of water should be maintained during sowing. After 3 days of sowing 5 cm of water should be maintained. During cultivation and fertilization, up to 5 days' water should not applied. During budding and fruiting 10 cm of irrigation. Before 10-15 days of harvesting water should be not in farm.	As per the irrigation information of rice, the irrigation for other crop has not been explain in detail. This report is only available in Nepali version.
Ministry of Agriculture and Livestock Development (MoALD, 2020)	Statistical Information on Nepalese Agriculture(2018/19).	Agricultural production, Crop command area.	–
IMP (2019)	Current and planned Cropping Intensity (CI)	For the baseline of 2019, CI: 132%, Target: 182% (upto 2025); 205% (2030); 230% (2045).	Only in context of Nepal, not district or province.
	Karnali Transfer (New scheme transfer)	Target for 40,000 ha of irrigation by 2029-2035.	
	Naumure Dam, Kapilbastu transfer (new scheme transfer)	Target for 42,000 ha of irrigation by 2027 to 2033	
	Bheri-Babai (completion of construction)	Current irrigation to 33,000 ha and target for 40,000 ha by 2025.	
	Rani Jamara (Completion of construction)	Current irrigation to 10,000 ha and target for 30,000 ha by 2025.	
	Mahakali III (Completion of construction)	Current irrigation to 5,000 ha and target for 25,000 ha by 2025.	
	Year Round Irrigation	39% (2019), 60% (2025), 80% (2030), 100% (2045).	
	Irrigation Efficiency	More than 50%	
ICIMOD (2010) GIS database	Agricultural command area	Six Terai districts within FtF-ZoI	
IMP (2019) GIS database	Surface Irrigation NCA from shape file database	Six Terai districts within FtF-ZoI	No such irrigation command area by groundwater.

Finally, relevant information such as total areas under agriculture as well as areas under major cereal crops (i.e., rice and wheat), and areas under surface irrigation system are reported in **Table 4-4**.

Table 4-4: Areas under agriculture and irrigation in Terai districts within the the Feed the Future Zone of Influence areas (Source: total agricultural command areas from ICIMOD (2010) and other information from IMP (2019)

District	Areas under agriculture (ha)			Areas under surface irrigation (NCA, ha)
	Total	Rice	Wheat	
Kapilbastu	96,255	58,000	31,000	15,915
Dang	119,497	36,508	12,655	27,548
Banke	65,191	31,900	18,022	25,076
Bardia	69,876	48,500	19,500	34,921
Kailali	102,457	71,250	34,500	29,554
Kanchanpur	61,981	45,796	31,433	16,874
Total	515,257	291,954	147,110	149,890

4.1 Data/Information gaps

- No adequate information/data on spatio-temporal distribution of various types of water demands within FtF-ZoI area. Accordingly, there is no mapping of water demand hot-spots and overlay with water availability (both surface water and groundwater) distribution to draw meaningful information in terms of conjunctive use planning.
- Water use inventory of both surface and groundwater resources, along with their location (latitude, longitude), and associated details are missing in literature.
- No estimation on projected future water demands (irrigation, domestic, etc.), neither in basin nor in command area or district or Palika levels, though there are some targets for future irrigated area.

5. Conjunctive Use Planning in the FtF-ZoI

This chapter first provides a brief overview of conjunctive use (CU) in terms of definition, benefits and potential challenges. It will then be followed by prospects for conjunctive use in the FtF-ZoI districts (Terai) in Western Nepal and potential strategies for realizing CU in the area.

5.1 Understanding conjunctive use

There is no robust definition of CU. For the purpose of this study, CU is defined as the simultaneous use of groundwater and surface water for consumptive use, productivity optimization, and achieving equity and environmental sustainability (FAO 1995; Foster et al., 2010; Evans et al., nd). This definition, however, may have many specifics and mean different things for different sectors/stakeholders. In either case, the pre-requisite for CU is the co-existence and availability for development/use of both groundwater and surface water. Conjunctive use offers a wide range of benefits as summarized in **Figure 5-1**, with potentials to contribute to economic and social outcomes. The benefits vary with hydrological and hydrogeological settings, however, the most important benefits that applies to most of the settings is considerable increase in agricultural production and productivity (in terms of improvements in overall cropping intensity and irrigation water productivity) through sustainable use of both surface and groundwater resources. A typical characteristic of CU is buffering high flow variabilities, both spatial and temporal, associated with the surface water-supply systems, due to various reasons including climate change and variabilities, by using large natural groundwater storage available in aquifers (Rao et al., 2004; Foster et al., 2010; Ticehurst and Curtis, 2019). The CU thus, offers an adaptation solution to climate change impacts on irrigation. Furthermore, CU is often a preferred way to confront with the problems such as groundwater salinization and water logging (Petherman et al., 2008; Foster et al., 2010; van Steenbergen et al., 2015).

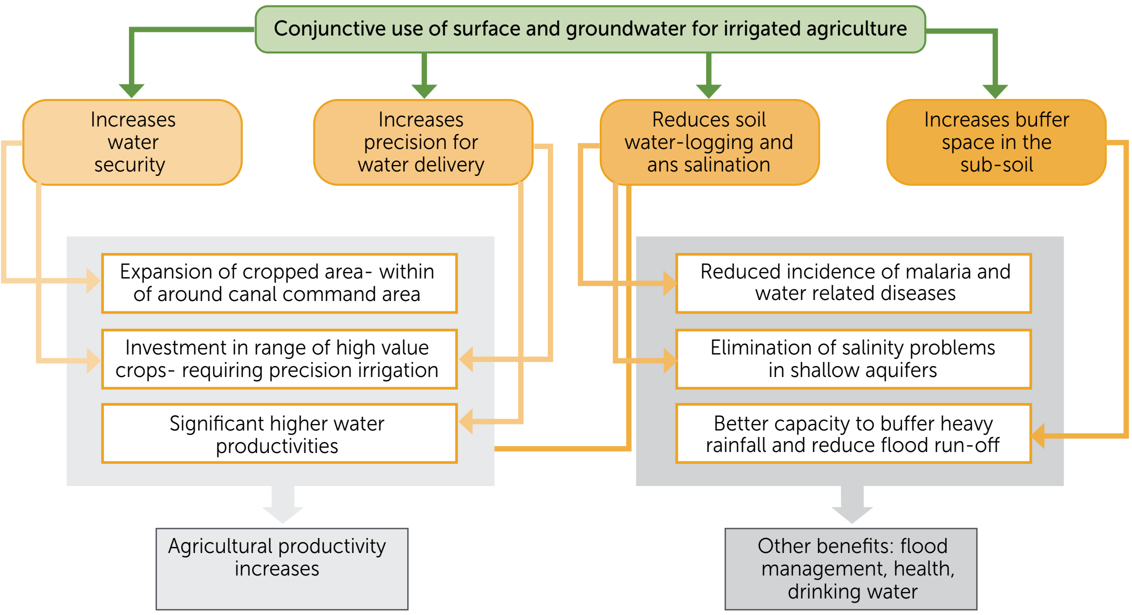


Figure 5-1: Range of potential benefits of conjunctive use of groundwater and surface water resources (Adapted from: Foster et al., 2010)

The CU is considered as an important water management practice for various social and economic outcomes since the 1960s (Bhattarai and Shakya, 2019). Though, CU generally happens by default where possibility exists, **planned CU** is yet to get adequate attention from policy and implementing agencies in terms of implementation in Nepal, and in much of South Asia. The absence of a strategic agenda to capitalize the potential for planned CU to support economic and social outcomes is one of the major impediments to meet both national and global goals such as sustainable development goals (SDGs). The type of interventions considered in terms of CU depends upon governance settings, infrastructure provisions, and water management arrangements (Evans et al., nd). Optimizing management and use of both surface water and groundwater resources, which have been developed separately, generally require substantial investment in capital, infrastructure, and reform of institutional structures, depending upon circumstances.

5.2 Prospects and challenges for conjunctive use in FtF ZoI

Prospects for CU in any area are generally assessed through analysis/evaluation of both primary and secondary data and subsequent consultation and validation with relevant stakeholders (e.g., Ticehurst and Curtis, 2019). After rigorous literature review and preliminary interactions with the stakeholders (a mix of government, non-government, and local) during group discussion in the inception meeting held virtually on 7th December, 2020, we have identified **15-key questions** to assess the prospects of CU. Those questions as well as their status in the FtF-ZoI districts (Terai) are provided in **Table 5-1**.

The unplanned CU practice has already been in many irrigation systems (Rajkulo + Groundwater) in Terai region of Nepal. However, there hasn't been adequate policy discussions on CU among water managers as well as relevant stakeholders. Nevertheless, there are ample opportunities/prospects for the planned CU in the FtF-ZoI districts due to its high recharge capacity, availability of SW resources, and potential for high agricultural yield attributed to fertile lands. The insights on prospects for CU identified through literature review and stakeholder interaction are reported in **Table 5-1**.

Table 5-1: 15-key questions for assessing prospects of CU and their status within the Feed the Future Zone of Influence (Terai), Western Nepal.

SN	Question/Aspects	Status in the FtF-ZoI (Terai)
1	Do both GW and SW co-exist? Can both resources be developed and used simultaneously?	Yes, though it highly depends upon location and cropping system in practice.
2	Is water/irrigation a limiting factor for production?	Water resources is available but irrigation access is still an issue as indicated in **Section-3** earlier. This is more of economic water scarcity rather than physical as we have a large reservoir of groundwater in Terai plain of the country
3	What are contributions of both SW and GW resources in total irrigation water supply? What is strategic role of groundwater for meeting spatio-temporal distribution of water demands?	Both GW and SW are available in most of the areas within the FtF-ZoI districts. Out of total irrigated area, GW so far is providing irrigation to 28% of the area, and rest are contributed by SW irrigation. As groundwater is available in aquifers in Terai, groundwater has strategic importance in meeting spatio-temporal distribution of water demands, if we can address the issue of economic water scarcity appropriately by minimizing energy costs.
4	Is there under-utilization of GW (both shallow and deep) resources?	Yes. Hydrogeological mapping indicates there are ample renewable GW resources in the Terai to support adequate irrigation for agricultural farm lands (Nepal et al., 2019). Only about 22% of available dynamic GW recharge in Terai is being utilized so far (Shrestha et al. 2018). There is a potential to use more without compromising sustainability, though a detailed scientific study is required to map spatio-temporal distribution of GW and safe/sustainable yield in relation to irrigated land and cropping system to put in place systems to better manage groundwater resources.
5	Is over-abstraction and subsequent depletion in GW an issue in the area?	There are adequate GW storage and replenishment is quite good from regional perspective. Groundwater recharge at a specific area is estimated to be as high as 600 mm/year, however around 450mm/year is expected to recharge at most of the Terai regions of Nepal (Bhattarai and Shakya, 2019), including FtF-ZoI districts. In addition to recharge potentials, Transmissivity value of shallow aquifer in the Terai region is high, ranging from less than 10 to over 10,000 m2/day (Saha et al., 2016). However, people have experienced issues of GW depletion at specific locations, such as at some locations in Kanchapur district.
6	Is water quality a serious constraint (or opportunity) for CU in agriculture?	No. This topic, however, requires more exploration
7	Are existing SW systems performing reasonably well (with minimal losses and adequate supply at the time of need)?	Inadequate water supply to meet water demands is generally an issue primarily associated with strong seasonality of SW systems, with more than two-thirds of rainfall as well as runoff are available in four rainy months (JJAS) only. Therefore, shortage of SW supplies in dry season necessitates the development of GW in many canal command areas.
8	Is there adequate understanding on CU and associated costs (e.g. added capital or operating expenses, new tehnical knowledge etc) and benefits among the farmers and relevant stakeholders?	Many farmers do not apply water to crops during critical stage of their requirements for various reasons including concerns on cost for water pumping. It has implication on crop yield and subsequently on productivity. Therefore, we may need intervention in the form of enhancing awareness on how appropriate irrigation (or lack of that) at different stages of crops affects the crop yield and profitability. The awareness in this aspect will help enhance their knowledge/understanding to apply irrigation appropriately and enhance yield and profitability. This topic however requires more exploration.
9	Do we already have CU practice in the area?	Unplanned CU is already in practice in most irrigation systems in Terai. Rajkulo and GW are being used simultaneously in some parts of the FtT-ZoI region. However, planned CU is yet to get into practice.
10	Can CU help improve performance of water supply system (reliable water supply and more efficiency) in the area? If yes, why is not getting adequate attention so far?	Yes, in general. Most of the irrigation systems in Terai, developed so far are fed by medium or small rivers, which almost entirely depend on the rainfall. A large portion of agricultural land in the Terai are under non-perennial irrigation, which need supplementary source of water, specifically groundwater, for dry season irrigation to ensure year-round-irrigation (YRI). This topic however requires more exploration.
11	Are both SW and GW managed/ governed by same authority?	No. This topic however requires more exploration.

Table 5-1: 15-key questions for assessing... cont'd

12	Does water supply agency (for irrigation) has adequate technical capacity and resources to plan and implement CU in the area?	No, especially in terms of designing as well as implementing effectively.
13	Is there adequate (spatial and temporal resolution) monitoring (both SW and GW) network and associated framework/ mechanism for database management and data access?	Quality data at higher resolution (both spatial and temporal) and framework/strategies for easy access of data does not exist so far. Especially, registration and monitoring of GW resources and abstraction with adequate spatial resolution is lacking.
14	Is there adequate scientific understanding on – i) spatio-temporal distribution of GW and SW availability and their development potentials?; ii) agricultural practice and productivity in finder resolution?; iii) farmers typology, variation in distribution of benefits across typologies, and differentiated strategies for CU for different typologies?	A detailed scientific study, using a range of tools such as participatory methods, raprid appraisal, and sophisticated models are required to ensure spatio-temporal distribution of groundwater availability as well as their use potential. Using participatory methods and rural appraisals can help gauge missing data through consultation with key stakeholders (in the absence of scientific studies). It also ensures process for CU be guided by initial appraisal and accompined by building up a better and more detailed database to adaptively guide the process as things move forward. Also, adequate understanding of agriculture practice and productivity at finer resolution as well as developing farmers typologies, and strategies to maximize benefits of CU across different typologies of farmers are yet to develop in a more systematic way.
15	Are there adequate efforts for strengthening and institutionalizing (with policies, programs, resources, capacity) of Water Users' Associations (WUAs) to create conducive environment for CU??	WUAs are key stakeholders to facilitate enhanced access of water to farm lands. However, there needs intervention in terms of enhancing their understanding/ knowledge on efficient water use, and strengthen capacity/awareness on those issues. Capacity building and awareness raising programs to enhance their understanding on CU is required for creating conductive environment for planned CU.

Notes: These status needs further verification from another round of stakeholder consultation to be carried out in near future.

In addition to the aforementioned prospects, there are challenges as well as impediments for promoting more rational and better planned CU in the FtF-ZoI districts (Terai). They are related to technical capacity, organizational structure, socio-political realities, inadequate emphasis on research-based development practices, data/information gaps, and promoting research as well as dissemination of findings. Some of the impediments documented by Foster et al. (2010) are relevant to this study area as well. The challenges and impediments are highlighted hereunder.

- Lack of reliable data records on groundwater availability and seasonal use and recharge patterns.
- Lack of reliable power supplies and inadequate rural electrification for groundwater pumping in canal command areas, that can be overcome using suitably designed solar irrigation pump (SIP) programmes for inclusive access to energy. SIPs can also help replace a vast amount of diesel pumps that are currently powering most irrigation in the FtF-ZoI districts (Terai).
- Lack of inventory and estimates of total water abstraction from groundwater from different locations within the FtF-ZoI areas.
- Inadequate understanding on spatio-temporal distribution of groundwater storage and groundwater development limits.
- Lack of awareness on value of going beyond operationally-simple self-supply system to more secure and robust CU solutions for various reasons including inadequate understanding as they are poorly taught in academic courses.
- Absence of integrated modelling of surface and groundwater systems, canal supplies, irrigation water requirements, and crop yield to generate scientific evidence of impacts of different combinations/ scenarios of CU systems on social and economic outcomes for CU planning.
- Lack of demonstration case studies and sound information and appropriate communication product(s) about opportunities/prospects of CU to communicate with different stakeholders
- Frequent split in responsibility for groundwater and surface water development and/or management, often results in a failure to identify and to engineer opportunities for planned CU, like in many other areas as reported by Foster et al. (2010).
- Inadequate emphasis to research for development programs in terms of allocation of funding.

5.3 Potential strategies for planned conjunctive use supporting further agricultural economic development in FtF-ZoI

For translating the prospects for planned CU in the FtF-ZoI districts (Terai) in Western Nepal to implementation, strategies, resources and commitments for addressing the challenges highlighted in **Section 5.2** are to be put in place. Following strategies as well as areas of investments are identified as appropriate for the FtF-ZoI districts (Terai);

- Establish enabling environment for public-private partnership and community-based investment to attract private sector for planned CU irrigation programs. Cost recovery, especially in terms of operation and maintenance could be a challenge for engaging private sector, however, appropriate model can be worked out through a couple of piloting in different settings to ensure more return with less investment of public fund and private sector will also be attracted. One piloting in this regard to understand what works and what does not could be a starting point.
- Appropriately design and implement monitoring system for both surface and GW resources (both quantity and quality) and use; and develop associated mechanisms/systems for database management, analysis and dissemination/access. The monitoring may include geographic database of several parameters such as cropping patterns, evapotranspiration/water demands, groundwater levels, canal alignments, and groundwater abstraction, among others.
- Ensure adequate quality of irrigation water (from both surface & ground water sources) by developing a guideline for quality requirements for irrigation water.
- Initiating a long-term campaign of education focusing on various risks/costs of water mis-management, benefits of CU, and pathways for planned CU.
- Adequate **investments** in hardware (system modernization and improved infrastructure), software (improved database), planning and management capacities, and institutional reforms,
- Interventions for improving water use efficiency through multiple pathways such as crop diversification to manage water demand, minimizing losses in irrigation system, and promoting micro-irrigation system where appropriate.
- **Research for development:** Integrated numerical modelling of irrigation canal flows, groundwater use and aquifer response, soil-water status and crop water use as shown in **Figure 5-2** for evidence-based evaluation of potential benefits with varying levels of spatial and temporal use of groundwater and distribution of surface water. Furthermore, research on social and institutional aspects of CU and its translation into development are equally important as sustainable development and management of water resources require understanding of both biophysical and socio-institutional aspects. It will ultimately improve CU efficiency and sustainability of water resources development and use. Apart from this, research on sustainable agriculture, soil erosion control, water quality/quantity restoration, and environmental risk assessment can support agricultural economy in a long-run.

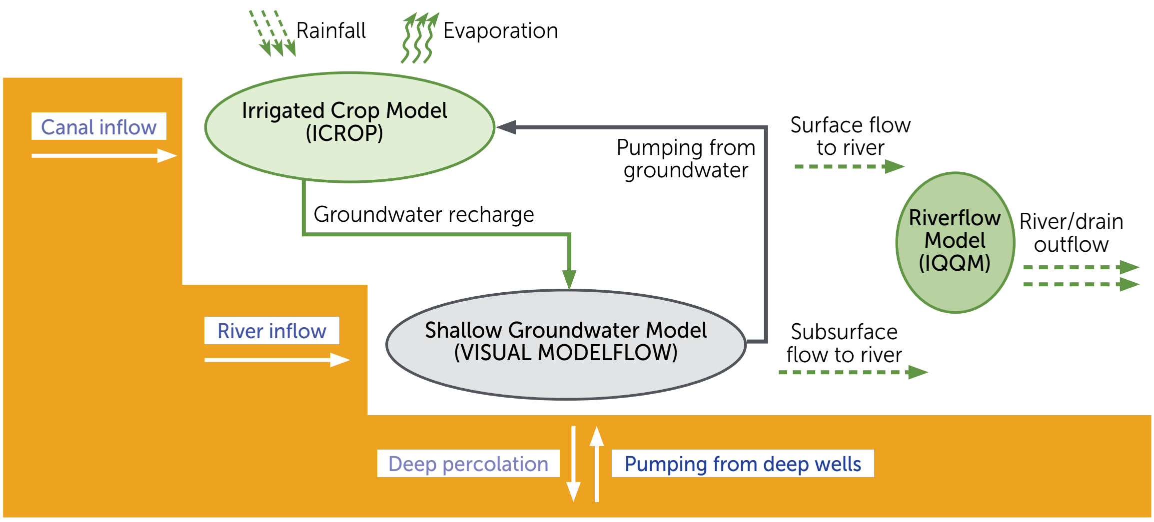


Figure 5-2: Schematic of integrated numerical modelling to evaluate conjunctive use options for improving the efficiency and sustainability of irrigated agriculture (Adapted from: Foster et al., 2010)

(Notes: the models named in the figure are indicative only. Any suitable model can be used for respective components, e.g. Soil and Water Assessment Tool (SWAT) for surface flow modeling; AquaCrop for irrigated crop model, etc.)

- Design and implement programs aimed at enhancing recharge and spring source protection are equally important to ensure sustained availability of groundwater sources to support planned CU. In case of Terai aquifer, as it is a part of Gangetic Plain, it's recommended to carry out a comprehensive study focusing on integrated modeling of the entire surface and groundwater system, including Cure region as well, and evaluate impacts of various types of interventions on Terai's groundwater system. In case of hills, studies aimed at delineating recharge areas and evaluating effectiveness of different types of interventions in those recharge areas in the form of recharge source/area protection wold be appropriate strategy to ensure availability of groundwater for supporting planned CU. The interventions, however, needs to be supported with evidence from research to have higher confidence on effectiveness of the interventions.
- Initiate/incentivize programs on enhancing profitability of the agricultural sector through various interventions such as encouraging appropriate commercial farming, minimizing costs of inputs, workable market linkage with aid of digital innovations, etc.
- Encourage integrated use and management of both surface and groundwater resources considering **river basin as a unit** and command areas as sub-units. It may require a reform in multiple fronts including water management institutions by eliminating fragmented structure of governmental institutions entrusted with various water management roles.
- Encourage solar irrigation programs in the areas where grid-connection is yet to reach or power supply is unreliable, while at the same time working to improve the energetic and water use delivery efficiency of diesel pump systems that predominate in Nepal.

6. Conclusions

Key conclusions generated from this study related to the four key study areas addressed below, namely, water availability, water demand, status of irrigation development, and conjunctive use (CU) planning in the FtF-ZoI region (Terai districts) are summarized as follows;

- **Water availability:** In terms of surface water, data on key hydrological features (e.g., catchment area, volume of water, water balance components, etc.) are available for nine basins/sub-basins in the region, albeit with varying level of details. Specific discharge across the river systems varies from 18.8 l/s/m2 (Upper Karnali, above Lalighat hydrological station) to 52.1 l/s/m2 (Mohana). Groundwater availability (MCM/km2/year) across the FtF-ZoI districts (Terai) varies from 0.11 in Dang to 0.48 in Kanchanpur. Aquifer yield is high in Bardia district (32 lps), followed by Kanchanpur (28 lps) and Dang has relatively lower yield (only 15 lps). From the perspective of planned CU, we need data/information on surface water availability for many southern rivers as well. It requires expansion of hydrological network in those rivers and developing a well calibrated and validated hydrological models.
- **Water demand:** It is not at this time possible to map water demand hot-spots, nor it is feasible to overlay such data with water availability (both surface and groundwater) distribution, and draw meaningful conclusions in terms of CU planning in the absence of a comprehensive study report on estimates of agricultural and other water demands and their spatio-temporal distribution. A detailed study on estimating water demands and their hot-spots with a higher resolution will address the aforementioned issue.
- **Status of irrigation development:** About 310,260 ha of land within the FtF-ZoI districts (Terai only) have irrigation facilities. Surface irrigation systems are designed to irrigate nearly 72% of total irrigated land whereas official groundwater wells cover only 28%. Official groundwater irrigation coverage varies across the FtF-ZoI districts (Terai only) from 13% (or 9,740 ha) in Bardia to 53% (or 24,248 ha) in Kanchanpur. Though continued efforts are put by the government sector, development partners and private sector to expand actual irrigation areas, there are still gaps and more investments are required to expand actual irrigation areas.
- **Prospects and potential strategies for planned CU:** Co-existence of both surface water and groundwater, under-utilization groundwater resources, and unreliable or inadequate water supply from surface water system that draws water from rain-fed and spring-fed rivers indicate a good prospect for planned CU in the FtF-ZoI districts (Terai). The challenges that problematize CU development, however, are mainly related to technical capacity, socio-political realities, inadequate emphasis (especially in terms of allocation of funds) on research-based development practices, and data/information gaps. Addressing the challenges and then translating the prospects for planned CU into reality requires workable strategies, mobilization of actors and resources, and political commitments. Establishing an enabling environment for public-private partnership and community-based investment to attract private sector for planned CU irrigation programs and a demonstration pilot in this regard to understand what works and what does not could be a starting point in this endeavor.
- **Knowledge gaps:** Literature on CU and groundwater in the Terai region of Nepal is almost non-existent. Similarly, there is a serious lack of reliable information on the extent of groundwater development, especially for privately operated command areas in the Terai. Knowledge base on surface water availability is relatively more, albeit with varying levels of details for different river systems in the region. However, a comprehensive modeling of entire hydrological system (both surface and groundwater) that covers all areas within the FtF-ZoI region using a coherent method/approach is missing. This point is a key, as appropriate and integrated CU and water resources planning will not be possible without tools, techniques, and data to driver scenario development to aid policy prioritization and decision-making. Furthermore, assessment/estimation of sustainable yield from different layers of groundwater aquifers and their spatial distribution are not well documented in literature. Understanding groundwater recharge process and dynamics are equally important to ensure sustained availability of groundwater for CU, however, information on groundwater recharge and potential recharge areas are not document, thereby adding constraints in designing appropriate inventions for groundwater recharge and source are protection. In terms of water demand, there is a lack of a comprehensive study estimating spatio-temporal distribution of water demands (for current and future periods), water use inventory of surface and groundwater resources, and performance assessment (both technical and economic) of existing irrigation systems. In sum, an integrated study for evaluating various scenarios of planned CU using a set of models to identify the most suitable scenarios for ensuring year-round-irrigation (YRI) at affordable costs on the irrigable lands in the FtF-ZoI districts (Terai) is needed for CU planning perspective.

References

Adhikari, B., Verhoeven, R. & Troch, P. (2009). Fair and sustainable irrigation water management in the Babai basin, Nepal. Water Science & Technology, 59(8): 1505-1513.

Adhikari, T., Rakhal, . B., Maharjan, . L. D. & Kushi , P. S. (2014). Determination of Flood Warning and Danger of Mohana and Macheli River. Submitted to Mercy Corps Nepal ; Submitted by GENESIS Consultancy (P) Ltd.

BBDMP, (2020). Bheri Babai Diversion Multipurpose Project (BBDMP) , Department of Water Resources and Irrigation, Goverment of Nepal. [Online] Available at: https://www.bbdmp.gov.np/pages/about-project [Accessed 7 9 2020].

Belt & Road News. (2020). The Belt & Road News. [Online] Available at: https://www.beltandroad.news/2020/01/02/20-development-projects-in-nepal-to-watch-in-2020/ [Accessed 1 12 2020].

Bhandari, G. (2014). Effect of Rainfall on the Yield of Major Cereals in Darchula District of Nepal. *International Journal of Environment,* 3(1): 2091-2854.

Bhandari, G. (2013). Effect of precipitation and temperature variation on the yield of major cereals in Dedeldhura Districts of Far Western Development Region, Nepal.. *International Journal of Plant, Animal and Environmental Sciences,* 3(1): 247-256.

Bhatta, B., Shrestha, S., Shrestha, P. K. & Talchabhadel, R., (2020). Modelling the impact of past and future climate scenarios on streamflow in a highly mountainous watershed: A case study in the West Seti River Basin, Nepal. *Science of the Total Environment, Journal Pre-proof.* https://doi.org/10.1016/j.scitotenv.2020.140156.

Bhattacharya, P., Samal, A. C., Majumdar, J. & Santra, S. C. (2009). Transfer of Arsenic from Groundwater and Paddy Soil to Rice Plant (Oryza sativa L.): A Micro Level Study in West Bengal, India. *World Journal of Agricultural Sciences,* 5(4): 425-431.

Bhattarai, DP & Shakya, NM. (2019). Conjunctive use of water resources in sustainable development of agriculture in Terai Nepal. *Journal of Institute of Engineering,* 15 (2): 210-217.

Bhattarai, P., Khanal, P., Tiwari, P., Lamichhane, N., Dhakal, P., Lamichhane, P., Panta, N. R & Daha, P. (2019). Flood Inundation Mapping of Babai Basin using HEC-RAS & GIS. *Journal of the Institute of Engineering,* TUTA/IOE/PCU, 15(2): 32-44.

Bista, R. B., Dahal, K. R. & Gyawali, R. P. (2018). A Review of Climate Change and its Effects in the Western Mountainous Water Basin of Nepal. *Hydro Nepal,* Issue 23, pp. 79-85.

Bohara, M. S. (2015). Physico-Chemical and Microbiological Analysis of Drinking Water Quality of Bhim Datta Muncipality of Kanchanpur. *Journal of Microbiological Research,* 1(1): 1-7.

CBS, (2011). Province Summary of Agriculture Census 2011. Available at: https://cbs.gov.np/province-summary-of-agriculture-census-2011/. [Assessed 21 9 2020]

CIP, (2020). *Community Irrigation Project (CIP).* [Online]. Government of Nepal; Ministry of Federal Affairs and Local Development (MoFALD); Department of Local Infrastructure Development and Agricultural Roads (DoLIDAR). Available at: cip-mis.aviyaan.com/cipweb/ [Accessed 12 8 2020]

Dahal, P., Shrestha, M. L., Panthi, J. & Pradhananga, D. (2020). Modeling the future impacts of climate change on water availability in the Karnali River Basin of Nepal. Environmental Research, 185: 109430. https://doi.org/10.1016/j.envres.2020.109430.

Dhami, B., Himanshu. S. K., Pandey., A. & Gautam, A. K. (2018). Evaluation of the SWAT model for water balance study of a mountainous snowfed river basin of Nepal. *Environmental Earth Sciences,* 77(21): 1-20. https://doi.org/10.1007/s12665-017-7210-8.

DJB, (2019). *Sustainable, Just and Productive Water Resources Development in Western Nepal under Current and Future Conditions.* Submitted by International Water Management Institute (IWMI), Nepal Office. Submitted to United States Agency for International Development (USAID).

DOA, (2018). Inter Provincial Dependency for Agricultural Development, Kathmandu: Department of Agriculture.

DWRI/GoN (2018). Irrigation and Water Resources Management Project (IWRMP). Project Completion Report (2008-2018). Department of Water Resources and Irrigation (DWRI), Governmetn of Nepal (GoN).

DWSSM, (2018). *Water Supply and Sanitation Status in Nepal,* Kathmandu: Department of Water Supply and Sewerage Management.

Evans WR, Evans RS, Holland GF (nd). Conjunctive use and management of groundwater and surface water. Groundwater governance: A global framework for country action (GEF ID 3726), Thematic Paper 2. pp 40. Available online at: https://www.zaragoza.es/contenidos/medioambiente/onu//newsletter15/968-eng-v2.pdf (accessed on 4th January, 2021)

FAO, (1985). Water quality for agriculture. Food and Agricultural Organization, Available at:http://www.fao.org/3/T0234E/T0234E00.htm. [Accessed 6 Nov 2020]

FAO, (1995). Land and water integration and river basin management. Proceedings of an FAO informal workshop, Rome, Italy, 31 January - 2 February 1993. Food and Agriculture Organization of the United Nations.

Foster S, van Steenbergen F., Zuleta J., Garduño H. (2010). Conjunctive use of groundwater and surface water – from spontaneous coping strategy to adaptive resources management. GW•MATE Strategic Overview Series No. 2, World Bank.

FTF (2016). Feed the Future Nepal 2015 Zone of Influence Interim Assessment Report. Rockville, MD: Westat.

GDC, 1994. Reassessment of the Groundwater development strategy for irrigation in the Terai (Volume 3 – Groundwater). Groundwater Development Consultants Ltd. (GDC). April, 1994. Submitted to the Government of Nepal, Department of Irrigation, Groundwater Resources Development Project.

Gurung, P., Bharati, L. & Karki, S. (2013). *Application of the SWAT Model to assess climate change impacts on water balances and crop yields in the West Seti River Basin.* Toulouse, France : Paul Sabatier University.

Gurung, S., Raut, N., Shrestha, S., Gurung, J., Maharjan, B. & Shrestha, S. (2015). Assessment of Groundwater Quality in Far Western Kailali District, Nepal. *Jacobs Journal of Hydrology,* 1(1): 1-9.

Hengaju, K. D. & Manandhar, U. (2015). Analysis on causes of deforestation and forest degradation of Dang district:using DPSIR framework. *Nepal Journal Environment Science,* 3: 27-34.

IFAD, 2020. Value chains for Inclusive Transformation of Agriculture, Nepal: International Fund for Agriculture Development (IFDA).

IMP (2018). Irrigation water use inventory – final report. Irrigation Master Plan (IPM), Preparation through Integrated River Basin Planning. Prepared by Lahmeyer International in May 2018 for Water Resources Project Preparation Facility, Department of Irrigation, Ministry of Irrigation, Government of Nepal.

IMP, (2019). Irrigation Master Plan Preparation through Integrated River Basin Planning, 2019; Prepared for Water Resources Project Preparatory Facility Department of Irrigation Ministry of Irrigation Nepal; Prepared by Tractebel Engineering GmbH in association with NIRAS and TMS.

Investopaper, (2020). Shikta Irrigation Project Starts Irrigation, Project Partially Completetd. [Online] Available at: https://www.investopaper.com/news/sikta-irrigation-project/ [Accessed 23 2 2021].

Jade Consult. (2020). Feasibility Study of Dams in Dang Valley. [Online] Available at: https://jadeconsult.com.np/service/irrigation-water-resources/ [Accessed 28 11 2020].

Khatiwada, K. R., Panthi , J., Shrestha, M. L. & Nepal, S. (2016). Hydro-Climatic Variability in the Karnali River Basin of Nepal Himalaya. MDPI, 74(6): 1-14.

MoALD, (2015a). *District Profile Banke,* Singha Durbar, Kathmandu: Government of Nepal, Ministry of Agricultural Development, URL: http://www.namis.gov.np/.

MoALD, (2015b). *District Profile Dang,* Singha Durbar, Kathmandu: Government of Nepal, Ministry of Agricultural Development, URL: http://www.namis.gov.np/.

MoALD, (2015c). *District Profile Kailali,* Singha Durbar, Kathmandu: Government of Nepal, Ministry of Agricultural Development, URL: http://www.namis.gov.np/.

MoALD/GoN (2020). Statistical information on Nepalese agriculture 2075/76 [2018/19]. Statistics and Analysis Sector, Planning and Development Cooperation Coordination Division, Ministry of Agriculture & Livestock Development (MoALD), Government of Nepal (GoN). Singha Durbar, Kathmandu, Nepal.

Mahat, K. R. & Shrestha, R. (2008). Metal Contamination in Ground Water of Dang District. *Nepal Journal of Science and Technology*, 9: 143-148.

Mishra, Y., Nakamura, Tai., Babel, M.S., Ninsawat, S. & Ochi, S. (2018). Impact of Climate Change on Water Resources of the Bheri River Basin, Nepal. MDPI, 220(10): 1-21.

MoH/GoN, New ERA, and ICF (2017). Nepal Demographic and Health Survey 2016. Kathmandu, Nepal: Ministry of Health, Government of Nepal (MoH/GoN).

Nepal S., Neupane N., Belbase D., Pandey VP & Mukherji, A. (2019). Achieving water security in Nepal through unravelling the water-energy-agriculture nexus. International Journal of Water Resources Development, 37 (1). https://doi.org/10.1080/07900627.2019.1694867.

Neupane, D., Gyawali, P. & Tamang, D., 2019. Study of River Channel Migration And Identification of Potential Sugarcane Cultivation Area in The Mohana-Macheli Watershed. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume IV-2/W5, pp. 223-229.

NMIP, 2014. *Nationwide coverage and Functionality Status of Water Supply and Sanitation in Nepal.,* Panipokhari, Kathmandu: Department of Water Supply and Sewerage Management, National Management Information Project.

Onta PR, Gupta AD and Harboe R (1991), Multistep planning model for conjunctive use of surface and ground-water resources, *Journal of Water Resources Planning and Management,* 117(6): 662-678.

Pakhtigian, E. L., Jeuland, . M., Dhaubanjar, S. & Pandey, V. P. (2019). Balancing intersectoral demands in basin-scale planning: The case of Nepal's western river basins. *Water Resource & Economics as Journal Pre-proof*, pp. 1-42. Doi: https://doi.org/10.1016/j.wre.2019.100152.

Pandey, V. . P., Dhaubanjar, . S., Bharati, L. & Thapa, B. R. (2020, a). Spatio-temporal distribution of water availability in KarnaliMohana Basin, Western Nepal: Hydrological model development using multi-site approach (Part-A). *Journal of Hydrology: Regional Studies*. https://doi.org/10.1016/j.ejrh.2020.100690.

Pandey, V. P., Babel, M. S., Shrestha, S. & Kazama, F. (2010). Vulnerability of freshwater resources in large and medium Nepalese river basins to environmental change. *Water Science & Technology,* 61(6): 1525-1534.

Pandey, V. P., Dhaubanjar, S., Bharati, L. & Thapa, B. R. (2019). Hydrological response of Chamelia watershed in Mahakali Basin, 650 (1): 365-383. https://doi.org/10.1016/j.scitotenv.2018.09.053.

Pandey, V. P., Dhaubanjar, S., Bharati, L. & Thapa, B. R. (2020, b). Spatio-temporal distribution of water availability in KarnaliMohana Basin, Western Nepal: Climate change impact assessment (Part-B). *Journal of Hydrology: Regional Studies.* https://doi.org/10.1016/j.ejrh.2020.100691.

Pandey, V. P., Manandhar, S. & Kazama, F. (2012). Water Poverty Situation of Medium-sized River Basins in Nepal. Water Resource Management, 26: 2475–2489.

PAANI, (2017). Lower Mahakali Watershed Profile: Status, Challenges And Opportunities for Improved Water Resource Management. USAID/Nepal: Program for Aquatic Natural Resources.

Panthi, J., Khatiwada, K., Shrestha, M. L. & Dahal, P. (2018). Water poverty in the context of climate change: a case study from Karnali river basin in Nepal Himalaya. *International Journal of River Basin Management,* 17(2): 243-250.

Pathak, D., 2018. Status of Groundwater Exploitation And Investigation In Terai And Inner Terai. *Bulletin of Nepal Hydrogeological Association,* 3: 77-83.

Paudyal GN and Gupta AD (1990), Irrigation planning by multilevel optimization, *Journal of Irrigation and Drainage Engineering,* 116(2): 273-291.

Perera, E. D., Hiroe, A., Shrestha, D., Fukami, K., Basnyat, D.B., Gautam, S., Hasegawa, A., Uenoyama, T. & Tanaka, S. (2015). Community-based flood damage assessment approach for lower West Rapti River basin in Nepal under the impact of climate change. Nat Hazards, 75: 669–699.

Petheram C, Bristow KL and Nelson PN (2008), Understanding and managing groundwater and salinity in a tropical conjunctive water use irrigation district, *Agricultural water management,* 95(10): 1167-1179.

PMAMP, (2019a). Third Annual Quaterly Progress Report of Fiscal year 2075/76, Nepal: Department of Agriculture and Livestock, Prime Minister Agriculture Modernization Project. Available at: https://pmamp.gov.np/sites/default/files/2020-05/PMAMP%20_PMU%20%281%29.pdf. [Accessed 23 9 2020].

PMAMP, (2019b). Annual Programme and Progress Report. Department of Agriculture and Livestock, Prime Minister Agriculture Modernization Project. Available at:https://pmamp.gov.np/sites/default/files/2020-08/PMAMP%20Annual%20Book%20.pdf. [Accessed 23 9 2020].

Rao, S. V., Bhallamudi, S. M., Thandaveswara, B. S. & Mishra, G. C. (2004). Conjunctive Use of Surface and Groundwater for Coastal and Deltaic Systems. Journal of Water Resources Planning and Management, 130: 255-267

Sapkota, B. (2003). Hydrogeological conditions in the southern part of Dang valley, mid-western Nepal. Himalayan Journal of Science, 1(2): 119-122.

Saha, D.; Zahid, A.; Shrestha, S. R.; Pavelic, Paul. 2016. Groundwater resources. In Bharati, Luna; Sharma, Bharat R.; Smakhtin, Vladimir (Eds.). The Ganges River Basin: status and challenges in water, environment and livelihoods. Oxon, UK: Routledge - Earthscan. pp.24-51. (Earthscan Series on Major River Basins of the World)

Shrestha SR, Tripathi GN and Laudari D (2018), Groundwater Resources of Nepal: An Overview. In Groundwater of South Asia (pp 169-193), Springer, Singapore.

Shrestha, N. (2017). *Projection of Futures Streams Flow and their Uncertainty West Rapti Basin, Nepal*. Master Thesis University of Twente, Netherlands.

Siddique, S., Bharati, L., Pant, M., Gurug, P., Rakhal, B & Maharjan, I. D. (2012). Climate Change and Vulnerability Mapping in Watersheds in Middle and High Mountains, of Nepal. Kathmandu: International Water Management Institute.

Talchabhadel , R., Nakagawa, H., Kawaike, K., Yamanoi, K. & Aryal, A. (2019). Future Assessment of Rainfall Erosivity (R-Factor) in West Rapti Basin, NEPAL Based on RUSLE And CMIP5 Climates Models. *Journal of Japan Society of Civil Engineers,* 75(2): 1141-1146.

Thapa, A., Shah, K. B., Pokheral, C. P., Paudel, R., Adhikari, D., Bhattarai, P., Cruz, N. J. & Aryal, A. (2017). Combined land cover changes and habitat occupancy to understand corridor status of Laljhadi-Mohana wildlife corridor, Nepal. *Eur J Wildl Res,* pp. 1-14.

Ticehurst JL & Curtis AL (2019). Assessing conjunctive use opportunities with stakeholders in the Murray-Darling Basin, Australia. Journal of Water Resources Planning and Management, 145 (5): 05019008.

Tripathee, N. (2018). Climate Change Impacts on Water Resources and Crop Yield in Mohana River Basin, Nepal. Master of Engineering in Water Engineering Management (Unpublished Thesis). Asian Institute of Technology, School of Engineering and Technology.

Urfels, A., McDonald, A. J., Krupnik, T. J. & Oel, P. R. (2020). Drivers of groundwater utilization in water-limited rice production systems in Nepal. *Water International,* 45(1): 39–59. https://doi.org/10.1080/02508060.2019.1708172.

Van Steenbergen F., Sasharat M. & Lashari B.K. (2015). Key challenges and opportunities for conjunctive management of surface and groundwater in Mega-Irrigation Systems: Lower Indus, Pakistan. Resources, 4: 831-856. doi:10.3390/resources4040831.

Wang, S. Y., Yoon, J. H., Gillies, R. R. & Cho, C. (2013). What Caused the Winter Drought in Western Nepal during Recent Years?. *Journal of Climate,* 26: 8241-8256.

WECS, (2011). Water Resources of Nepal in the Context of Climate Change. Singha Durbar, Kathmandu, Nepal: Water and Energy Commission Secretariat.

WHO, (2020). Arsenic. [Online] Available at: https://www.who.int/news-room/fact-sheets/detail/arsenic [Accessed 22 October 2020].

WRPPF, (2020a), Final Report, WRPPF: Preparation of Priority River Basins Flood Risk Management Project, Nepal.

WRPPF, (2020b), Feasibility Report: West Rapti Basin, WRPPF: Preparation of Priority River Basins Flood Risk Management Project, Nepal.

WRPPF, (2020c), Flood Forecasting and Early Warning System: Mohana – Khutiya Basin, WRPPF: Preparation of Priority River Basins Flood Risk Management Project, Nepal.

WRPPF, (2020d). Detailed Engineering Design: Mohana – Khutiya Basin, WRPPF: Preparation of Priority River Basins Flood Risk Management Project, Nepal.

WRPPF, (2016). Package 6- Pre-Feasibility Study Report of Mid-Hill Lift Irrigation Project, Kathmandu: Water Resources Project Preparatory Facility.

WRS, (2002). *Water Resources Strategy Nepal.* Singha Darbar, Kathmandu: Water and Energy Commission Secretariat (WECS), p. 1-143.

Yadav, I. C., Singh, S., Devi, N.L., Mohan, P. M., Tater, P. S. & Shakya, B. M. (2012). Spatial Distribution of Arsenic in Groundwater of Southern Nepal. *Reviews of Environmental Contamination and Toxicology,* 125-139.

Yadav, S. K. (2002). Hydrological Analysis for Bheri- Babai Hydropower Project Nepal. Unpublished M.Sc. Thesis, Norwegian Agency for International Development (NORAD).

Annexes

Annex 2-1 (a): List of surface irrigation projects under Department of Water Resources and irrigation (formerly, Department of Irrigation) within the FtF-ZoI districts and their key features (Source: IMP, 2019)[5]

SN	Name of Irrigation System	Source River Name	Headwork Location District	YoC	VDC	Ward	GCA (ha)	NCA (ha)	Main Canal Discharge (lps)	Main Canal Length (Km)	Program	Funds
1	BACHHELA IP	Bachchela Khola	Kanchanpur	1996	Daijee	3	149	130	300	2.6	ILC	IDA
2	BAGUN IP	Bagun Khola	Kanchanpur	1996	Daijee	4	249	240	320	4.7	ILC	IDA
3	BAIJNATH IP	Tatopani Khola	Kanchanpur	2002	Daijee	3	70	58	179	2.0	NISP	IDA
4	BALUWA IP	Baluwa Nala	Kanchanpur	1999	Raikawar Bichawa	2	156	140	250	2.4	NISP	IDA
5	BELDADI IP	Anokhi Khola	Kanchanpur	2000	Jhalari	4	87	75	275	1.8	NISP	IDA
6	BRAHMDEO IP	Haldekhal Khola	Kanchanpur	1996	Mahendranagar	9	218	200	500	2.5	ILC	IDA
7	CHUNEPANI IP	Trishule Khola	Kanchanpur	2002	Suda	7	105	90	180	3.4	NISP	IDA
8	DHUNAGADHI IP	Mahakali	Kanchanpur		Mahendranagar	10	101	81	0	1.8	NISP	
9	HATHITHALA IP	Dherthum Khola	Kanchanpur	1998	Daijee	7	16	15	200	5.1	NISP	IDA
10	JARAHI NALA IP	Jarahi Nala	Kanchanpur	1999	Krishnapur	6	151	140	300	1.1	NISP	IDA
11	JHALE IP	Mahakali	Kanchanpur		Daijee	3	44	35	0	1.2		
12	KALA PANI IP	Sihali and Toti Khola	Kanchanpur	1998	Jhalari	3,4,5,6	1098	600	600	8.5	NISP	IDA
13	KHARGADA IP	Mahakali	Kanchanpur		Jhalari	2	155	124	0	6.1		
14	MAHAKALI IP	Mahakali	Kanchanpur	1987	Mahendranagar		14020	11600	28316	394.3	DOI	GoN
15	MALERIYA NALA IP	Maleriya Khola	Kanchanpur	1992	Chandani	4	543	500	750	4.8	SIP	GoN
16	MOHANA IP	Machheli Khola	Kailali	1987	3 VDCs		3194	2000	2000	12.0	NG	MG/ KORE
17	PATHARIYA K IP	Mahakali	Kanchanpur		Daijee	6	63	50	0	2.0		
18	RAUTELA IP	Rautela Khola	Kanchanpur	1999	Mahendranagar	1,9	288	164	350	2.0	NISP	IDA
19	SIDHANATH IP	Tusare Kamitate Khola	Kanchanpur	2002	Mahendranagar	8	83	75	260	4.0	NISP	IDA
20	SINGHPUR IP	Mahakali	Kanchanpur		Krishnapur	9	185	148	0	2.4		
21	UPPER JARAHI IP	Mohana Khola	Kanchanpur	2004	Krishnapur	5,6	511	409	300	3.6	NISP	IDA
22	AAMARAWATI IP	Dudjhari Khola	Kailali		Baliya	8,9	115	92	0	3.2		
23	BAGDHAULI IP	Doda Nadi	Kailali	1992	Darakh	5,6	408	326	1200	6.5	NG	GoN
24	BANBEHADA IP	Shiva Ganga Nadi	Kailali	2001	Chaumala	8	49	40	120	1.2	NISP	IDA
25	BANIKULO IP	Pathariya Khola	Kailali		Thapapur, Joshipur		2152	2145	4250	13.4	NISP	
26	BHAJANI IP	Kandra Nadi	Kailali	1996	Bhajani	2, 3, 4, 5, 7, 8	833	700	2150	12.2	ILC	IDA
27	BHURSA IP	Kulariya Nadi	Kailali	2002	Manuwa	4, 5, 8, 9	528	485	1660	5.2	NISP	IDA
28	BIJULIYA BANDHA IP	Kandra Nadi	Kailali	2002	Khailad	2	107	95	220	2.0	NISP	IDA
29	BUDHIYAM IP	Chuniyathai Khola	Kailali	2002	Sugarkhal		141	113	350	2.0	NISP	IDA
30	GHURGHI BADH IP	Sharma Nadi	Kailali	2006	3 VDCs		1625	1100	2300	12.5	NISP	DOI

5 ADB: Asian Development Bank; DDC: District Development Committee; DOI: Department of Irrigation; EEC: Early Education and Care Funding; GCA: Gross Command Area; GoN: Government of Nepal; IDA: International Development Association; IWRMP: International Women in Resources Mentoring Programme; MG/ KORE: KORE Mining; NCA: Net Command Area; NISP: National Industrial Symbiosis Programme; UNFC: United Nations Framework Classification for Resources; USAID: United States Agency for International Development; VDC: Village Development Committee; YoC: Year of Construction.

Annex 2-1 (a): List of surface irrigation... cont'd.

SN	Name of Irrigation System	Source River Name	Headwork Location District	YoC	VDC	Ward	GCA (ha)	NCA (ha)	Main Canal Discharge (lps)	Main Canal Length (Km)	Program	Funds
31	KHURKHURIA IP	Baluwa Nadi	Kailali	1996	Chaumala	1,7	745	650	1300	8.0	ILC	IDA
32	KHUTI IP	Kala Khola	Kailali	1987	Shripur, Beladevipur		3620	1500	5660	13.9	UNCF	A
33	MACHHELI IP	Machheli Khola	Kailali	1996	Godawari	9	39	32	200	3.0	ILC	IDA
34	MOHANA IP	Machheli Khola	Kailali	1987	Godawari, Malakheti, Krishnapur		3194	2000	2000	12.0	NG	MG/KORE
35	MUNUWA IP	Kulariya Nadi	Kailali	1996	Manuwa	5, 6, 7	6	5	1150	2.6	ILC	IDA
36	NULEKADA IP	Kada Khola	Kailali		Munuwa	7	500	500	0	19.6		
37	PATHRAIYA IP	Pathariya Khola	Kailali	1974	Bauniya, Joshipur, Dodhara		3360	2000	2000	22.9	NG	GoN
38	PATRENI IP	Rajma Khola	Kailali	2000	Mahanyal	9	28	24	75	1.7	NISP	IDA
39	PRATAPPUR IP	Chori Khola	Kailali	1998	Pratappur	2, 3, 4, 6, 9	705	650	1950	7.0	NISP	IDA
40	RAJBADHUWA IP	Bauraha Khola	Kailali	1999	Sandepani	2, 3, 4	512	368	1500	6.1	NISP	IDA
41	RANIJAMARA IP	Bahula Nadi	Kailali	1991	11 VDCs		24516	15000	5400	24.12	NG	GoN
42	RATIPUR IP	Kandra Nadi	Kailali		RamsikharJhala	1	52	50	0	3.91		
43	SONAH AJRAILI IP	Kulariya Nadi	Kailali	2001	Manuwa	1, 2, 3	203	180	500	3.09	NISP	IDA
44	TEDI IP	Surma Nadi	Kailali	1996	Ratanpur, Basauti	7	1757	1500	3300	12	ILC	IDA
45	BABAI IP	Babai Nadi	Bardiya	1999	9 VDCs		35421	13500	18000	223.0	NISP	GoN
46	BARAGADE JAMTI NEULAPUR IP	Jhamati Khola	Bardiya		Neulapur, Baganaha	2,3,4,8,9 & 4,5,6,7,8,9	1614	1291.2	0	15.1	NISP	
47	BHADA NALA IP	Bhada Khola	Bardiya		Dhadhawar	6	85	68	0	7.5	ILC	
48	BHAJANA IP	Sateriya Nala	Bardiya		Deudalka	5,7,9	78	62.4	0	1.4	NISP	
49	CHAPLA NALA (CHHEGRARE BANDH) IP	Chapa Nala	Bardiya		Manpur Mainapokhar	4,6	222	177.6	0	7.9	Central	
50	DHODHARI TARA TAL IP	Babai Nadi	Bardiya	2006	3 VDCs		5313	4250.4	0	70.5	ILC	IND
51	KALIGAUNDI IP	Orai Khola	Bardiya	1992	Sivapur	9	254	203.2	0	8.3	NISP	ADB/N
52	KUTHARA LAGANIYA IP	Kuthara Khola	Bardiya	2001	Belawa	1,3,4,9	410	328	0	4.8	NISP	IDA
53	MANPUR MAINAPUR IP	Sateriya Nala	Bardiya		Manpur Mainapokhar	1,2,5,7,8,9	553	530	0	13.9	ILC	IND
54	PAHARE KHOLA IP	Jurpani Khola	Bardiya		Dhadhawar	7	33	26.4	0	1.1	ILC	
55	PRATAP PUR IP	Orai Khola	Bardiya		Neulapue	1,2,4	268	214.4	0	7.7	ILC	
56	RAJA PUR IP	Geruwa Nadi	Bardiya		10 VDCs		17140	13000	35000	28.0	ILC	
57	REHU KHOLA IP	Sephahi Khola	Bardiya	2000	Deudalka, Motipur	6 &5	307	245.6	0	10.9	ILC	IDA
58	SURYAPATUWA IP	Patachuli Khola	Bardiya	1997	2 VDCs		1280	1024	0	9.4		ADB
59	AM KHOLA IP	Am Khola	Banke		Kohalpur	4	84	60	130	1.3	NISP	
60	BANIYABHAR IP	Jethi Khola	Banke	2002	Naubasta	5,6	104	100	200	3.3	NISP	IDA
61	BETAHANI LIFT IP	Dundawa Khola	Banke	2001	Bethani	1,5,9	159	150	100	5.0	ILC	IDA
62	BINAURE IP	Binaure Khola	Banke		Binauna	9	126	100.8	200	0.8		
63	CHHARAHA IP	Chharabawa Khola	Banke		Binauna	8	151	120.8	400	1.5		
64	CHISAPANI NAUBASTA IP	Man khola	Banke	1996	Naubasta	2	264	211.2	300	4.0	NISP	IDA
65	DANDUWA IP	Danduwa Khola	Banke	1968	12 VDCs		1596	1250	206	15.9	Central	GoN
66	DHAULAGIRI LIFT IP	Kiran Nala	Banke		Bageshoweri	1	211	200	250	1.0	ILC	
67	DHOLIYA IP	Dholiya Khola	Banke		Khaskushma	6,7	73	58.4	130	2.5		
68	DHUMAIYA IP	Dhumaiya Khola	Banke	1996	Benauna	4,5	227	220	0	5.4	NISP	IDA
69	DUNDRA KHOLA IP	Dundra khola	Banke		Kachanapur	4	25	23	60	1.6	NISP	
70	FATTE PUR IP	Rapati River	Banke		Fatte Pur	7,8,9	1910	1528	8500	13.0	ILC	

Annex 2-1 (a): List of surface irrigation... cont'd.

SN	Name of Irrigation System	Source River Name	Headwork Location District	YoC	VDC	Ward	GCA (ha)	NCA (ha)	Main Canal Discharge (lps)	Main Canal Length (Km)	Program	Funds
71	GHAIYA TAL IP	Pedari Nala,Ghaiya Tal	Banke	2002	Raniyar Pur	1	179	120	140	0.0	ILC	IDA
72	JHIJHARI BANGESAL IP	Bangesal Khola	Banke	1999	Mahadevpuri	2	101	100	200	2.5	ILC	IDA
73	JHINGAURA NALA	Jethi Nala	Banke		Titihiriya	8,9	135	125	430	2.5	ILC	
74	KIRAN NALA IP	Kiran Nala	Banke	1997	Radhapur	4,5,7,8,9	205	165	330	1.3	ILC	ADB
75	KUTHARA LAGANIYA IP	Kuthara Khola	Bardiya	2001	Belawa	1,3,4,9	410	328	0	4.8	NISP	IDA
76	MAKAI BARI IP	Man Khola	Banke		Naubasta	2	62	49.6	400	0.4		
77	MAN KHOLA IP	Man Khola	Banke		Chisapani	1	33	32	31	0.6	NISP	
78	MAN KHOLA LIFT IP	Man Khola Pumping	Banke		Sonpur	9	33	30	25	1.1	ILC	
79	NIBUWA FARM IP	Rohini Khola	Banke	1997	Kohalpur	4	166	150	285	6.5	NISP	ADB
80	PARUWA IP	Paruwa Sota River	Banke	1996	Kachanapur	8	104	100	0	2.5	ILC	IDA
81	PATHARIYA B IP	Pathariya Khola	Banke		Baijapur	4,7	47	37.6	50	2.5	NISP	
82	RAJ KULO IP	Rapati River	Banke		Baijapur & Binauna	1,2,5,6,9 & 1,2,3,4,6,7,8,9	1723	1520	2510	16.1	Central	
83	SIKTA IP	Rapati River	Banke		34 VDCs		31003	18068	50000	47.0		
84	SIMALGHARI SURFACE LIFT IP	Pump	Banke		Sonpur	9	35	30	28.5	0.8	ILC	
85	SUIYA KHOLA IP	Suiya Khola	Banke		Katkuiya	3,8,9	50	30	40	1.6	NISP	
86	THAPUWA TITITARIYA IP	Jethi Nala	Banke		Tititariya	1 to 7	104	58	100	0.0	ILC	
87	THULO KHOLA IP	Thulo Khola	Banke		Chisapani	2	42	35	50	1.1	NISP	GoN
88	THURE IP	Paruwa Sota River	Banke		Mahadevpur	7	95	76	0	2.1		
89	AAMKHOLI CHIRA IP	Aamkholi	Dang		Panchkule	5	117	93.6	0	1.6		
90	AGHARA IP	Katuwa Khola	Dang		Saudiyar	1	74	59.2	0	1.7		
91	AMARE BANDH IP	Hapur Khola	Dang		Narayanpur	7	178	142.4	0	6.2		
92	AMBAPUR KULO IP	Katuwakhola	Dang		Tribhuwannagar	5	135	130	0	2.5		
93	ARGHARA IP	Katuwa Khola	Dang	2002	Tribhuban Municipality & Sodiyar	2 & 1	238	170	800	4.9	NISP	IDA
94	ARJUN KHOLA IP	Arjun Khola	Dang	1992	Chailahi	3,4,5	500	400	1960	1.5	GON / ECC	EEC
95	ASHWARA KULO IP	Bhamake Khola	Dang		Tulsipur	11	160	128	0	3.2		
96	AWSARA DABARA IP	Bhamaki Khola	Dang		Tulsinagar Municipality	11	144	115.2	0	4.0	IWRMP	
97	BADHARE KULO IP	Ranigadh	Dang		Hapur	4	167	133.6	0	1.5		
98	BAHUNDANDA A IP	Siwar Khola	Dang		Gorahi Municipality	7,8,9	401	300	1200	6.5	CARE Nepal	
99	BAHUNDANDA B IP	Sewarkhola	Dang		Tribhuwannagar	7,8,9	152	121.6	0	4.1		
100	BALIM KHOLA IP	Balim Khola	Dang		Rampur	4	189	151.2	0	3.2		
101	BANGAUNLE KULO IP	Sapgaiyan Sota	Dang		Narayanpur	6	268	210	0	3.3		
102	BARAU KHOLA IP	Barau Khola	Dang	2002	Dhanaraui	4,7	129	103	330	1.5	NISP	IDA
103	BASGAJEDI IP	Tharubas Mulgeriya,Gaera Khola	Dang		Hapur	7	36	30	21	1.8	IWRMP	
104	BASTIKHOLA IP	Basti Khola	Dang		Shantinagar	7,8,9	330	315	0	4.5		
105	BAYALE SIMTARAM IP	Bhimalegaira/Keraghari- Bhitri Khola	Dang		Shantinagar	2,3,4	243	224	0	5.0		
106	BELA CHHAP IP	Karanga Khola	Dang		Bela	8	136	125	0	3.4		
107	BELA IP	Lomari Khola	Dang		Bela	4	285	250	0	5.0	MIN	IND
108	BELANNE KULO IP	Simpani	Dang		Dhikpur	3	215	172	0	2.8		
109	BELGHARE IP	Hatti Khola	Dang	1989	Shrigau	1,2,3	165	150	0	5.0	GON	USAID
110	BHAISAKURMA IP	Sisne Khola	Dang	2002	Laxmipur	2,3,4,5 &9	219	212	300	8.2	NISP	IDA

Annex 2-1 (a): List of surface irrigation... cont'd.

SN	Name of Irrigation System	Source River Name	Headwork Location District	YoC	VDC	Ward	GCA (ha)	NCA (ha)	Main Canal Discharge (lps)	Main Canal Length (Km)	Program	Funds
111	BHAMAISOTA IP	Jyamire/Hapur Khola	Dang		Narayanpur	1	243	200	0	5.6		
112	BHAMAKI IP	Babai	Dang		Duruwa	5	48	38.4	0	1.6		
113	BHAMAKI KUMALGADI IP	Bhamaki Khola	Dang		Pawannagar	3,5,9	231	200	492	4.0	IWRMP	
114	BHOTE DAHA IP	Bhote Daha	Dang		Rampur	4,7	16	12.8	0	1.7	NISP	IDA
115	BUDHAURE BANDH IP	Larena Sota	Dang		Narayanpur	8	202	161.6	0	2.7		
116	BULBULE IP	Uneria Khola	Dang	1989	Tripur	8	61	48.8	0	3.6	ADB/N	ADB/N
117	CHAMAI SATGAIYA IP	Katuwa Khola	Dang	2002	Saudiyar & Tulsinagar Municipality	3,4 & 1,2	407	378	0	6.6	NISP	IDA
118	CHARANGE GAD IP	Charange Daha	Dang		Rampur	6,7	71	60	0	2.4	MIN	IDA
119	CHAUWA KHOLA IP	Chauwa Khola + Hurhure Khola	Dang	1996	Manpur & Duruwa	7 & 5	530	450	1125	2.0	ILC	IDA
120	CHHOTE KULO IP	Bhamki Khola	Dang		Pawannagar	1 to 4	125	114	314	4.3	IWRMP	
121	CHILIYA MANIKAPUR IP	Kakrawa Khola	Dang	1996	Gadhawa	5	101	100	300	2.5	ILC	IDA
122	CHIREGAD IP	Chiregad Khola	Dang	2000	Shantinagar	1	67	54	0	4.3	NISP	IDA
123	CHIREGADH IP	Chiregadh	Dang		Shreegaun	1,2,3,4,5	306	244.8	0	7.3		
124	CHUNPOLE IP	Chunpole Khola	Dang		Bagmare	5 & 6	49	47	22	3.5	MIP	
125	CHYANTI KHOLA IP	Chantte Khola	Dang	2002	Purandhara	1,2,3	152	130	455	3.3	GON	IDA
126	DANGI CHIRA IP	Dangi Chira	Dang		Phulbari	4	110	88	0	1.8		
127	DOHOTE KULO IP	Bansghari khola	Dang		Hanspur	4	51	38	66.5	1.5	IWRMP	
128	DUDHARAS KULO IP	Sangram Khola	Dang		Bijauri	1	150	128	0	4.0	MIP	GoN
129	GAIRAGAUN IP	Katuwa Khola	Dang	1999	Ghorahi	2	92	73.6	0	4.6	NISP	IDA
130	GANGDI IP	Gangdi Khola	Dang	1995	Rajpur	7,8	83	66.4	0	1.4	ADB/N	ADB/N
131	GHORAHAMANPUR IP	Rapti River	Dang	1989	Gadhawa	2,4,6,7,8	517	500	1350	7.0	GON	GoN
132	GHORTENI IP	Sirse Khola	Dang	1994			29	23.2	0	0.8	ADB/N	ADB/N
133	GOBARDIHA BADKAPATH IP	Rapti River	Dang	1997	Gobardiha 2 to6		453	400	1350	9.4	ILC	ADB
134	GUHAR KHOLA IP	Guhar Khola	Dang		Bijauri/Manpur	6,8,9/6,8	160	128	0	17.8		
135	GURJE KHOLA IP	Gurje Khola	Dang		Hapur	2,3	110	106	0	3.0		
136	HALWAR IP	Guhar Khola	Dang	1989	Halwar	6	507	500	1500	13.0	GON	GoN
137	HAPUR GURJE IP	Gurje Khola	Dang	2000	Hapur	2	71	56.8	0	2.3	NISP	IDA
138	HASANAPUR IP	Paddako Mul	Dang		Urahari	5	121	96.8	0	4.1		
139	HEKULI KULO IP	Chiregadh	Dang		Hekuli	7	221	200	0	6.0		
140	JAMERA KULO IP	Sakram Khola	Dang		Manpur	3	355	330	0	8.0		
141	JURAH KULO IP	Jurah	Dang		Hapur	3	66	134	0	1.8		
142	JYAMIRE GURJE KHOLA IP	Gurje/Jyamire Khola	Dang		Narayanpur	3	154	150	0	3.1		
143	KACHELA KACHILI IP	Guhar Khola	Dang	1996	Urahari	1 to 4	198	200	1000	3.7	ILC	IDA
144	KALAMGHARI IP	Gurje Khola	Dang		Narayanpur	1	49	116	0	3.6		
145	KANDA KHUTI IP	Kandakhuti	Dang		Rampur	8,9	124	125	0	4.7		
146	KANJUWAR IP	Pathkuli Khola	Dang	1989	Duruwa	1	51	40.8	0	3.3	ADB/N	ADB/N
147	KARJAHI SATGAYA KULO IP	Katuwa Khola	Dang	2006	Tulsinagar Municipality & Saudiyar	2 & 2,4	435	406	1090	6.9	MIP	DOI
148	KARMATUWA IP	Gargi Sota Khola	Dang	1995	Tripur	12	59	47.2	0	2.4	SI	GoN
149	KATUKI IP	Laraina Sota	Dang		Dhikpur	2	175	140	0	3.2		
150	KATUWA KHOLA IP	Katuwa Khola	Dang	1996	Tribhuban Municipality	6,11	307	245.6	320	5.4	ILC	IDA

Annex 2-1 (a): List of surface irrigation... cont'd.

SN	Name of Irrigation System	Source River Name	Headwork Location District	YoC	VDC	Ward	GCA (ha)	NCA (ha)	Main Canal Discharge (lps)	Main Canal Length (Km)	Program	Funds
151	KHACHAREY KULO IP	Gurje Khola	Dang	2006	Saudiyar	7,8,9	547	500	1500	5.6	MIP	DOI
152	KIMUWA GAJARI MUL IP	Gajari Mul	Dang		Duruwa	7	169	135.2	0	3.4		
153	KORBANG IP	Baulaha Khola	Dang		Danaruai	5	80	50	0	1.5	IWRMP	
154	KORC IP	Agrang Khola	Rolpa		Masina	9	13.2812	13.28	0	4.2		
155	KUNHARA BANDH IP	Sarema Sota	Dang		Narayanpur	6	135	133	0	2.1		
156	KWANG KHOLA IP	Hapur Khola	Dang		Urahari	2 to 5	220	200	700	4.3	GON	
157	LARENE SOTA IP	Larena Sota Khola	Dang		Dikupur	1,5,7	57	45	125	2.4	MIP	
158	LOHADABRE IP	Patre Khola	Dang		Dhikpur & Duruwa	5,7,8,9 & 3,4	867	800	1900	7.6	IWRMP	
159	LOHASUR RATANPUR IP	Sewarkhola	Dang		Tribhuwannagar	11	98	78.4	0	2.8		
160	LOVELY KULO IP	Chauwa Khola	Dang		Manpur & Duruwa	7,8 & 5	429	350	750	2.7	MIP	
161	MAG KHOLA IP	Dharapani Khola	Dang	2001	Bagmare		29	46	0	1.4	NISP	IDA
162	MAH KULO IP	Baulaha Khola	Dang	2001	Bagmare	4,5	103	82.4	0	4.3	NISP	IDA
163	MAJH KULO D IP	Baulaha Khola	Dang		Bagmare	4	101	80.8	300	1.8	NISP	
164	MALWARE BELDHAKUWA IP	Guhar Khola	Dang		Manpur/Duruwa	3,4,5/6,7,8	487	389.6	0	7.9		
165	MALWARE KULO IP	Guhar Khola	Dang		Manpur & Dunuwa	3,4,5 & 6,7,8	937	800	1800	8.3	MIP	
166	MANAKAPUR KULO IP	Guhar Khola	Dang		Bijauri	3	204	200	0	4.0		
167	MANI KULO IP	Lama Khola, Pakariyajhiki Sota	Dang		Bijauri & Manpur	4,5 & 7	121	90	270	2.2	DDC/VDC/DOI	
168	MANIKAPUR IP	Bhumhe Khola	Dang	1999	Pawan Nagar	3,9	87	75	300	4.4	ILC	IDA
169	MANPUR KULO IP	Guhar Khola	Dang		Bijauri	9	116	92.8	0	3.4		
170	MANPURE KULO IP	Gwar Khola	Dang	1994	Manpur & Bijaure	1 & 5 to 8	407	393	919	6.0	IWRMP	ADB/N
171	MAYA KHOLA IP	Maya Khola	Dang		Hekuli	4	74	50	0	3.1	NISP	
172	MUGRAIDHA KHOLA IP	Mugraidha Khola	Dang		Rajpur	1,2,3	133	106.4	0	3.3		
173	NAWALPURE KULO IP	Sirsota	Dang		Urahari	4	797	800	0	7.1		
174	OINERA IP	Oniera khola	Dang		Hapur	6,7,9	32	25.6	157	4.0	IWRMP	
175	ORDAWA IP	Babai Khola	Dang		Dharna	4	105	84	0	5.2		
176	PADHDHA KULO IP	Padhdha Sota	Dang		Tarigaun	4	134	107.2	0	3.4		
177	PARSADUWA	Chiregar Khola	Dang	1995	Shrigau	3	177	141.6	0	6.4	ADB/N	ADB/N
178	PATHKAULI BANDH	Guhar Khola	Dang		Duruwa	1	175	172.5	0	3.3		
179	PATU KHOLA IP	Patu Khola	Dang		Tarigau	5,7,8	335	300	825	4.1	MIP	
180	PHALAKPUR IP	Bhulke Khola	Dang	1989	Sonpur & Chaulahi	4,5,6 & 8	347	229	0	7.7	DOI	GoN
181	PRAGNNA IP	Rapti River	Dang		Lalmatiya, Shishaniya, Sonpur & Chailahi	1 to 9; 1 to 9; 1 to 9; 1,6 to 9	6092	5800	0	218.0	GON	KUBET
182	PRASIYA KULO IP	Khadkapur	Dang		Gangaparaspur	9	125	100	0	2.6		
183	RAJPURE KULO IP	Sewar Khola	Dang		Saudiyar	5	179	143.2	0	5.5		
184	RAKSE CHOUR IP	Sir Khola	Dang		Tulsipur	1,2	47	40	0	5.3	MIN	IND
185	RAMPURRSIMAL TAR IP	Balim Khola	Dang	1995	Rampur	3	147	130	300	2.0	MIP	ADB/N
186	RANIGAD IP	Ranigad Khola + Santi Khola	Dang	1996	Halwar	3,4	217	173.6	320	3.7	ILC	IDA
187	RANIGAR KHOLA IP	Rani Khola	Dang		Halwar	3,4	24	19.2	0	1.9		
188	RANSING KHOLA IP	Ransing, Mathura Khola	Dang		Gobardiha	1	146	140	0	4.1		
189	RATANPUR IP	Hapur Pendya Khola	Dang	1997	Hapur	8,9	170	125	250	3.9	NISP	ADB
190	RATGAIYAN KULO	Gwar Khola	Dang		Manpur & Bijauri	2,6 & 7	635	500	1300	6.0	IWRMP	

Annex 2-1 (a): List of surface irrigation... cont'd.

SN	Name of Irrigation System	Source River Name	Headwork Location District	YoC	VDC	Ward	GCA (ha)	NCA (ha)	Main Canal Discharge (lps)	Main Canal Length (Km)	Program	Funds
191	RATNAPUR IP	Sewat Khola	Dang	1997	Ghorahi	1	116	92.8	0	4.5	ILC	IDA
192	SALGARI IP	Bandre Khola	Dang	2001	Panchkule & Bagmara	1,2 & 1	231	200	410	5.9	NISP	IDA
193	SATGAULE SIR KULO IP	Patu Khola	Dang	2001	Tulsipur	3 to 5	415	332	0	5.9	NISP	IDA
194	SAUDI KULO IP	Hapur Khola	Dang	1989	Narayanpur	3,4,5,7	564	451.2	1600	11.8	GON	GoN
195	SAUDIYAR KULO IP	Sewar Khola	Dang		Saudiyar	5,6,7,9	254	225	0	4.2		
196	SEMARI MOTIPUR KULO IP	Rapti River	Dang		Gadhawa	6,7	129	103.2	0	2.1		
197	SHIR KHOLA IP	Patu Khola	Dang		Tulsinagar Municipality	8,9,10	654	523.2	300	3.5	ILC	
198	SHIR KULO IP	Bhamki Khola	Dang	2002	Pawan Nagar	3,4	92	73.6	450	1.5	NISP	IDA
199	SHIRKATT IP	Patu Khola	Dang		Tulsinagar Municipality	1 to 7	118	94.4	0	3.6	GON	
200	SIMPANI IP	Simpani	Dang		Hekuli	9	137	109.6	0	2.7		
201	SIRKATTI IP	Raintakura/Sisnekhola	Dang		Pawannagar	2,3,4,8	143	140	0	3.5		
202	SONPURNARTI IP	Singai Khola	Dang	1994	Sonpur	4,5	26	20	0	2.3	ADB/N	ADB/N
203	SUPAILA IP	Supaila Khola	Dang		Gobardiha	8,9	609	487.2	0	7.2		
204	SUPAILA PARASHPUR IP	Kapalihawa Khola	Dang		Gangaparsapur	2,3,5	251	201	645	3.2	ILC	
205	SUPAILA PARASPUR PARSENI IP	Kapalihawa	Dang		Gangaparaspur		192	153.6	0	3.4		
206	THATI KULO IP	Sisne Khola	Dang	2001	Tribhuban Municipality	4	31	25.66	200	1.6	NISP	IDA
207	URAHARI JASPUR HEMNAGAR KULO IP	Guhar Khola	Dang		Urahari/ Tarigaun	3,4,5/ 2,3	324	259.2	0	5.5		
208	BANGANGA IP	Banganga River	Kapilbastu	1980	12 VDCs		10734	6250	0	20.5	DOI	GoN/ADB
209	BARAIPUR (KANCHANIA) POND [LIFT] IP	Kanchania Khola	Kapilbastu		Baraipur & Udaypur	4 & 8	70	52	0	2.2	NITP	
210	BETHI IP	Bethi River	Kapilbastu		Banskhor	7,8,9	489	400	0	4.0	ILC	
211	BHADEHAR IP	Jamuwar Khola	Kapilbastu	2001	Gauri	1,2,3,4,5,6	419	320	0	3.8		
212	BHUTAHA K IP	Bhutaha Khola	Kapilbastu	1996	Nandanagar	5,5,7,8	2000	1600	0	8.5		
213	BIKRAMSOTA IP	Ban Ganga River	Arghakhanchi	2001	Simalpani	1	62	50	180	1.9	NISP	IDA
214	DHUNGE SERA IP	Gurmuwa Khola	Arghakhanchi	1995	Sidara	5	12	10	0	2.7	ADB/N	ADB/N
215	DOHANI IP	Jamuwar Khola	Kapilbastu	1996	Dharmpaniya	8	512	480	1000	5.5	ILC	IDA
216	DUBIYA POND [LIFT] IP	Gudrung River,Spring & Runoff	Kapilbastu		Dubiya	4	61	55	55	1.2	NITP	
217	GALAHA BANGUWA IP	Sukli Khola	Kapilbastu		Badganga	4	381	304	0	4.0		
218	GANGAULIA GAUTIARIWA IP	Gangauliya Nala	Kapilbastu		Gajehada	3	165	165	550	2.0	IWRMP	
219	GHAGHAWA IP	Ghaghawa Nala [Jamuwa Khola]	Kapilbastu	1999	Patana & Hathausn	1,7 & 8	476	375	0	5.9	NISP	IDA
220	HUDARWA IP	Hudarwa Khola	Kapilbastu	1997	Hathausa	6	373	350	0	2.4		
221	JABAI SAKUNI IP	Jabai Khola	Kapilbastu	1996	Chanai		1757	400	1500	7.0	ILC	IDA
222	JAHADI IP	Jamwar Khola	Kapilbastu	1996	Jahadi		233	233	0	2.1	ILC	IDA
223	KANCHANIYA IP	Gandak	Kapilbastu		Sisuwa	2,3,5,6	309	300	0	2.2	ILC	
224	KARMA IP	Karma Nala	Kapilbastu	1992	Banskhor	5	126	100	0	4.3	DOI	GoN
225	MAHENDRAKOT IP	Gurmuwa Khola	Kapilbastu	2003	Mahendra Kot	1,9	433	400	0	8.3	NISP	IDA
226	PATHERDAIYA IP	Surahi Khola	Kapilbastu	2002	Pathardehiya & Bahadurgunj	1 ,2 & 6	1374	700	1005	7.8	NISP	IDA
227	PAWARTAR IP	Ban Ganga River	Arghakhanchi	1989	Simalpani	2 & 5	55	50	165	4.1	ILC	GoN
228	PHULIKA IP	Marthi Khola	Kapilbastu	1996	Fulika	1	582	350	0	4.3		
229	RANGAPUR SAGAR POND [LIFT] IP	Mashayia River & sagar	Kapilbastu		Rangapur	1	50	48	0	2.5	NITP	
230	SAYAR BANDH IP	Surahi Khola	Kapilbastu		Bahadurgunj	3,4,5	756	400	0	4.2		
231	SINGREYGHAT IP	Banganga River	Kapilbastu	2006	4 VDCs		2594	2523	0	6.0	MIP	DOI

Annex 2-1 (b): List of constructed Community Irrigation Projects (CIPs) within the Feed the Future Zone of Influence (in Terai) (Source: CIP, 2020)

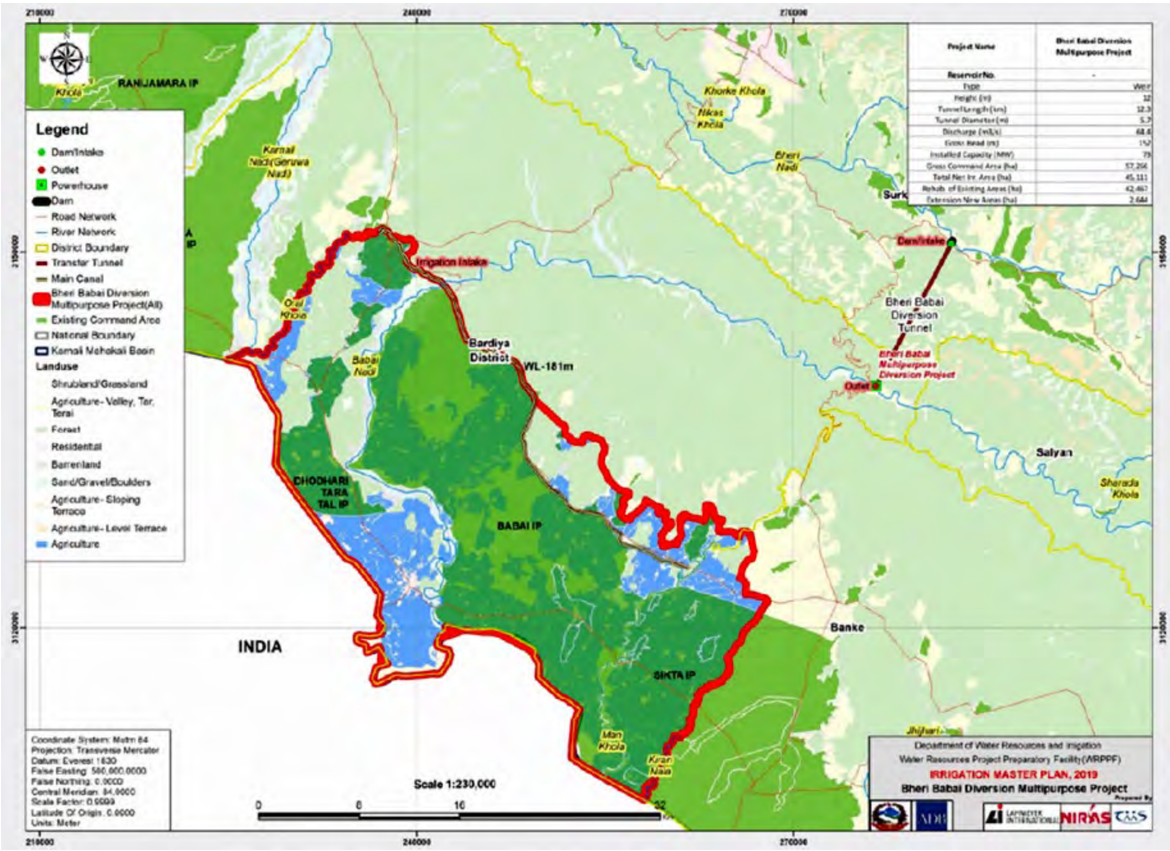
Completed Irrigation infrastructure by CIP under Batch 1				
SN	District	irrigation system project	Command area (ha)	Rehab/New
1	Kapilvastu	Kothibandh	138	Rehab
2		Jankalyan Lift ISP	102	New
3	Dang	Ghatte Khola Irrigation Sub-Project	152.6	Rehab
4		Hanumaanpur Irrigation Sub-Project	86.02	Rehab
5		Matheuri Irrigation Sub-Project	40.5	Rehab
6		Lamitara Irrigation Sub-Project	53	Rehab
7	Kailali	Charidanda ISP	46.8	New
8		Khairala Khola Bunda	24.5	Rehab
9		Salley Khola	14.7	Rehab
10		Vijayanagar Ranifata	81.35	Rehab
11	Kanchanpur	Jhaule Irrigation Sub-Project	96.5	New
12		Bachhela Irrigation Sub-Project	134.3	Rehab
13		Jadepani Irrigation Sub-Project	50	New
Completed Irrigation infrastructure by CIP under Batch 2				
S.no.	District	irrigation system project	Command area (ha)	Rehab
1	Kapilvastu	Khairahawa Bandh Surface Irrigation Project	199.75	New
2		Gangatahawa Surface Irrigation Scheme	66.8	Rehab
3		Beti Khola Surface Irrigation Scheme	108	Rehab
4		Sapahi Bandh Surface Irrigation Scheme	147.3	Rehab
5		Jaypur Bandh Surface Irrigation Scheme	56.2	Rehab
6		Surjabaliya Surface Irrigation Scheme	113	Rehab
7		Birpur Bandh Surface Irrigation Scheme	66.6	Rehab
8		Kajarari Bandh Surface Irrigation Scheme	66.3	Rehab
9		Horila Bandh Surface Irrigation Scheme	200	Rehab
10		sukulekothi Surace Irrigation scheme	164	New
11	Dang	Jungkholi Tulsigunj Irrigation Sub-Project	49.4	Rehab
12		Budkulo Irrigation Sub-Project	110	Rehab
13		Bukakhola Irrigation Sub-Project	51.46	Rehab
14		Badahara Irrigation Sub-Project	98	New
15		Jeetpur Irrigation Sub-Project	47.8	New
16		Ratanpur Irrigation Sub-Project	199.75	Rehab
17	Kailali	Patali Khola	23.24	New
18		Jetha Khola	10.2	Rehab
19		Samudaek ISP	22.4	New
20		Piyale Khola	24.55	New
21		Kuliwan Kafalgaira	25	New
22		Ghatekhola Patreeni Irrigation Sub Project	25	New
23		Thuligad sera Irrigation Sub Project	15.5	New
24		BelJhari	14.58	Rehab
25		Sanajiling Â Irrigation Sub Project	10.19	New
26		Baddi kulo Irrigation Sub Project	53.93	Rehab
27		Kamalanadi Dadiya ISP	23.63	New
28		Chakkale Pani Irrigation Sub Project	14.77	New
29	Kanchanpur	Jarahi Irrigation Sub-Project	50	Rehab
30		Tultule Irrigation Sub-Project	62	Rehab
31		Beldandi Irrigation Sub-Project	67	Rehab
32		Sisne Irrigation Sub-Project	94	New
33		Siddhanath Irrigation Sub-Project	40.5	Rehab
34		Baijnath Irrigation Sub-Project	58.6	Rehab
Completed Irrigation infrastructure by CIP under Batch 3				
S.no.	District	irrigation system project	Command area (ha)	Rehab/new
1	Kapilvastu	Basudawa Surface Irrigation Scheme	46	New
2		Ratanpur Surface Irrigation Scheme	140	New
3		Pichurakhi Surface Irrigation Scheme	42	New
4		Bharatghat Surface Irrigation Scheme	145	New
5	Dang	Thute Tari Irrigation Sub-Project	61	Rehab
6		Ganari Irrigation Sub-Project	41	Rehab
7		Sauri Lift Irrigation Sub-Project	75.8	New
8		Parseni Taal Irrigation Sub-Project	42	Rehab
9		Uttar Aamrai Irrigation Sub-Project	76	New
10		Larina Irrigation Sub-Project	74	Rehab
11		Wuyinariya Irrigation Sub-Project	103	Rehab
12		BulBula Sota Lift Irrigation Sub-Project	51	Rehab
13		Dongpur Lift Irrigation Sub-Project	40	Rehab
14		Balim Irrigation Sub-Project	177	Rehab
15		Kalimati Kulo/Balichhopa Irrigation Sub-Project	44	Rehab
16		Balapur,Bengwa Sota Irrigation Sub-Project	50	Rehab
17		Bhamki Lift Sichai Yojana	64	Rehab
18	Kailali	Jarahibadh ISP	158.15	New
19		Amfata ISP	63.47	Rehab
20		Sursuriya ISP	49	New
21		Dharpadayara dharapani &Uttiseni ISP	25	New

Annex 2-1 (b): List of constructed Community Irrigation Projects (CIPs)... cont'd.

S.no.	District	irrigation system project	Command area (ha)	Rehab/new
22		Dharapani Gajani ISP	17	New
23		Gumatadi ISP	25	New
24		Pandon ISP	21	New
25		Vudka Khola ISP	25	New
26		Okhaldunga ISP	25	New
27		Khar khola ISP	19	New
28		Kulibadh ISP	55.25	New
29		Basanta ISP	199	New
30		Taranager ISP	68	Rehab
31		Kandra ISP	195	New
32		Vadaile Khola	84	New
33		Barkha Kataini	80	New
34		Lathaiya ISP	52	Rehab
35	Kanchanpur	Jay Gurbaba ISP	49	New
36		Doda ISP	78	New
37		Aam Ghat ISP	76	New
38		Bagun Khaola ISP	87	New
39		Lalpaniya ISP	41	New
		Completed Irrigation infrastructure by CIP under Batch 4		
S.no.	District	irrigation system project	Command area (ha)	Rehab/new
1	Kapilvastu	Kundre Khola Irrigation Scheme	120	New
2		Mahendra Kot Surface Irrigation Scheme	46	Rehab
3		Due muhane kulo Surface Irrigation Scheme	58	Rehab
4		Samayathan Taal Irrigation scheme	66	Rehab
5		Siraka bandh & pond irrigation Scheme	198	Rehab
6		Pratappur Pond Irrigation Scheme	66	Rehab
7		Dhanchaura taal & Ghorahi Bandh Irrigation Scheme	146	Rehab
8		Abhirav lift Irrigation system	75	New
9	Dang	Machaute kulo ISP	100	Rehab
10		Manikapur Kulo ISP	145	Rehab
11		Goyalaghari, Malpani ISP	198	Rehab
12		Bastikhola I	199	Rehab
13		Chiregad khadakpur Kulo ISP	54	Rehab
14		Daunne khola ISP	43	Rehab
15		Amuwa khola ISP	115	Rehab
16		Bogati Kulo I	103	Rehab
17	Kailali	Mohana lift ISP	77	New
18		Ampani ISP	25	New
19		Barpani Badikathai Irrigation Sub-Project	25	New
20		Badhya Khola ISP	25	New
21		Singasaini Jaryapani ISP	16	New
22		Mathilo kulo ISP	25	New
23		Tallo kulo ISP	25	New
24		Madhe Bagrawa ISP	25	New
25		Ruenikot ISP	23	New
26		Barpani-2 Irrigation Sub-Project	75	New
27		Batiyani ISP	109	New
28		Namuna Lift ISP	77	New
29		Jadyapani ISP	25	New
30		Talsaini ISP	25	New
31		Machali Khola ISP	47	Rehab
32		Kachali ISP	25	New
33		Juryapani	40	New
34		Patreni ISP	40	New
35		Badki kulo lift ISP	94	New
36	Kanchanpur	Purbi raoutela ISP	40	New
37		Tumadi Chanmari ISP	40	New
38		Tumadi Khola ISP	40	New
39		West Rautela ISP	58	New
40		Ghatal ISP	40	New
41		Shankarpur ISP	41	New
42		Pathriya ISP	50	New
43		Odali Khola ISP	40	New
44		Chishapani ISP	41	New
45		Band Khola ISP	40	New
46		Banhara ISP	64	New
47		Sundariphata ISP	123	New
48		Khanyakhola ISP	63	New
49		Dhungadi ISP	40	New
50		Sidhanath ISP	50	New
51		Kunjagalli lift ISP	59.5	New
52		Banahara Katan lift ISP	63.75	New

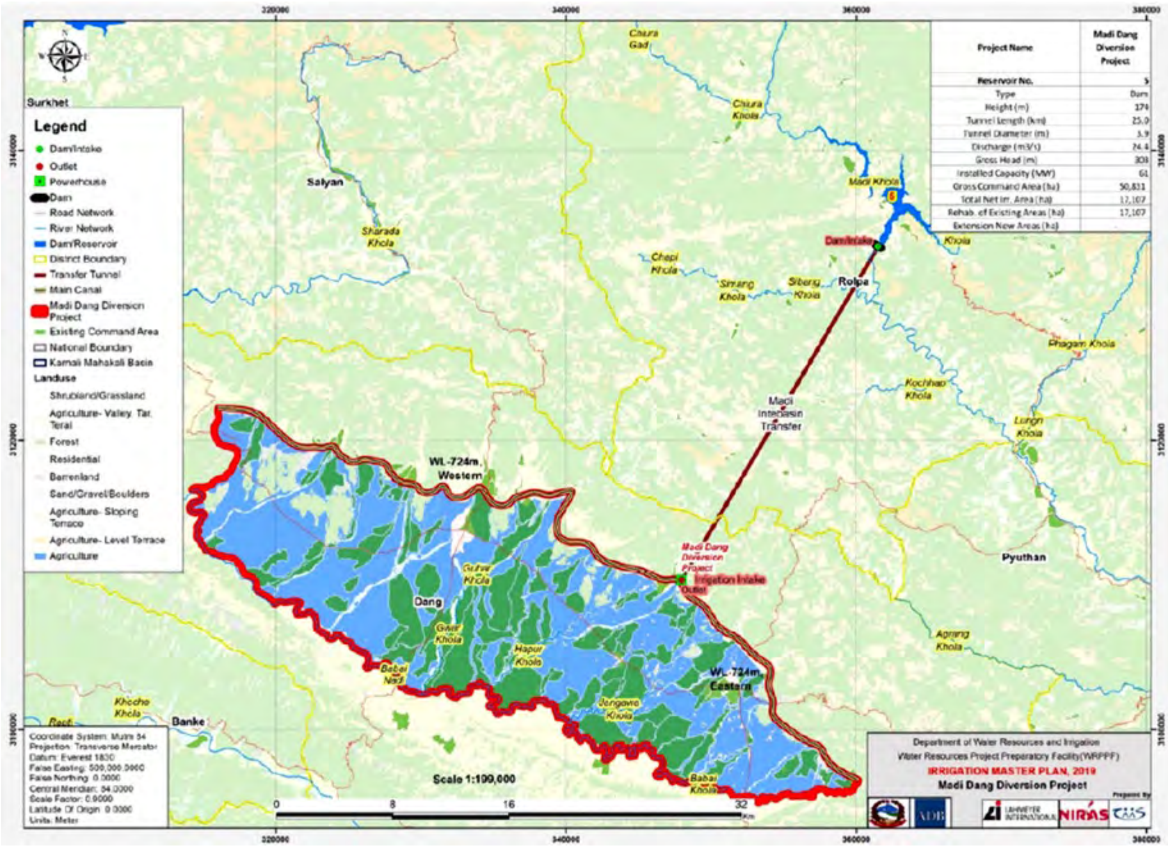
Annex 2-1 (c): List of under-construction Community Irrigation Projects (CIPs) within the Feed the Future Zone of Influence (in Terai) (Source: CIP, 2020)

Under construction irrigation project by CIP under Batch 3				
SN	District	irrigation system project	Command area (ha)	Rehab/New
1	Kailali	Tengana Khola ISP	46	New
2	Kanchanpur	Jhale khola ISP	40	New
Under construction irrigation project by CIP under Batch 4				
SN	District	irrigation system project	Command area (ha)	Rehab/new
1	Kapilvastu	Jamunbagiya Lift Irrigation Scheme	66.38	New
2		Mahuwa Lift Irrigation Scheme	174	New
3		Pandedih Lift Irrigation Scheme	88	New
4		Gudrung Rangai Lift Irrigation Scheme	83	New
5		Janachetana Lift Irrigation Scheme	75	New
1	Kailali	Jarjariya ISP	195	New
2		Vulvuliya ISP	127	New
3		Tiule khola ISP	68	New
4		Junali Lift ISP	114	New

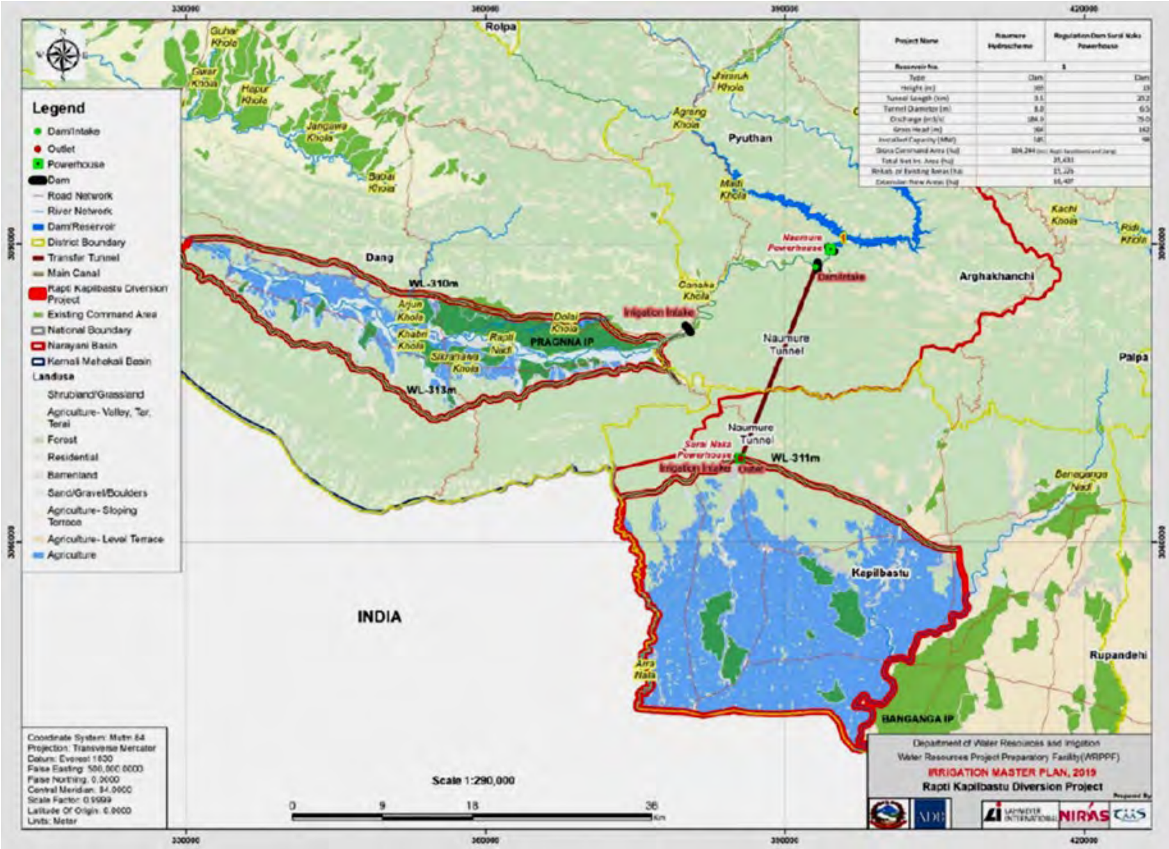


Annex 2-2 (a): Location and associated details of Bheri-Babai Diversion Multipurpose Project (BBDMP) (Source: IMP, 2019)

Annex 2-2 (b): Location and associated details of Karnali Diversion Project (Source: IMP, 2019)



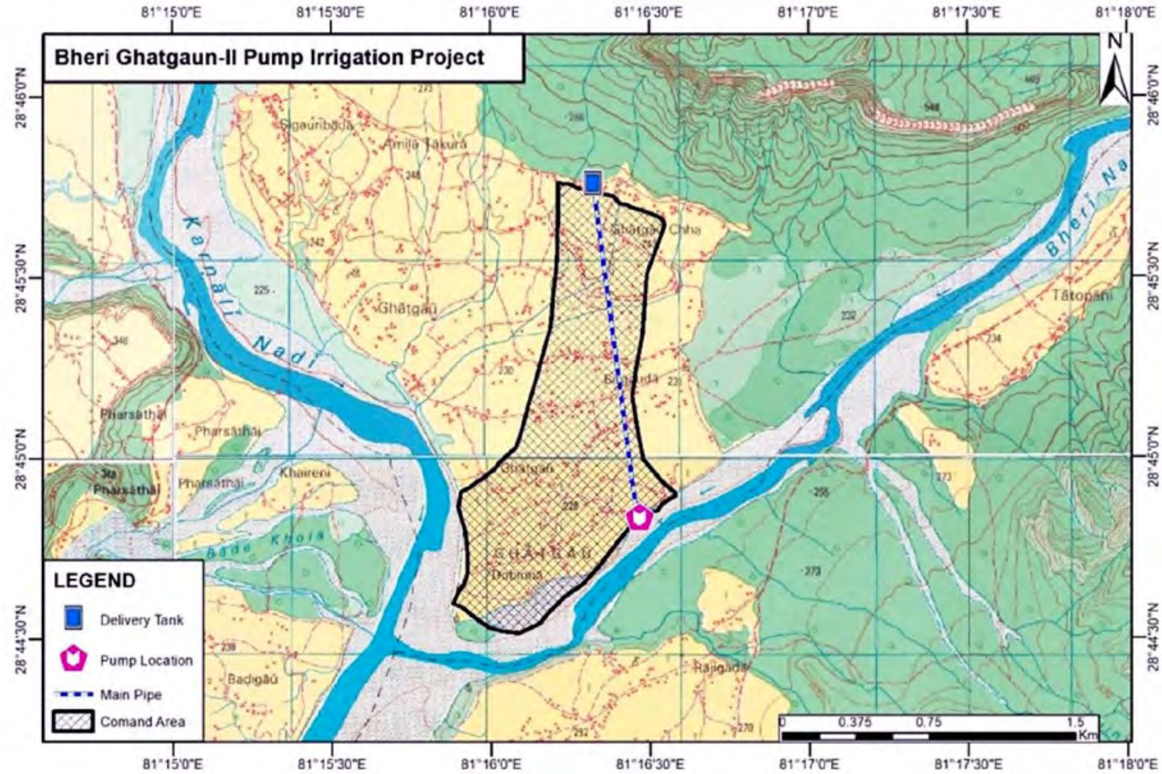
Annex 2-2 (c): Location and associated details of Madi-Dang Diversion Project (Source: IMP, 2019)



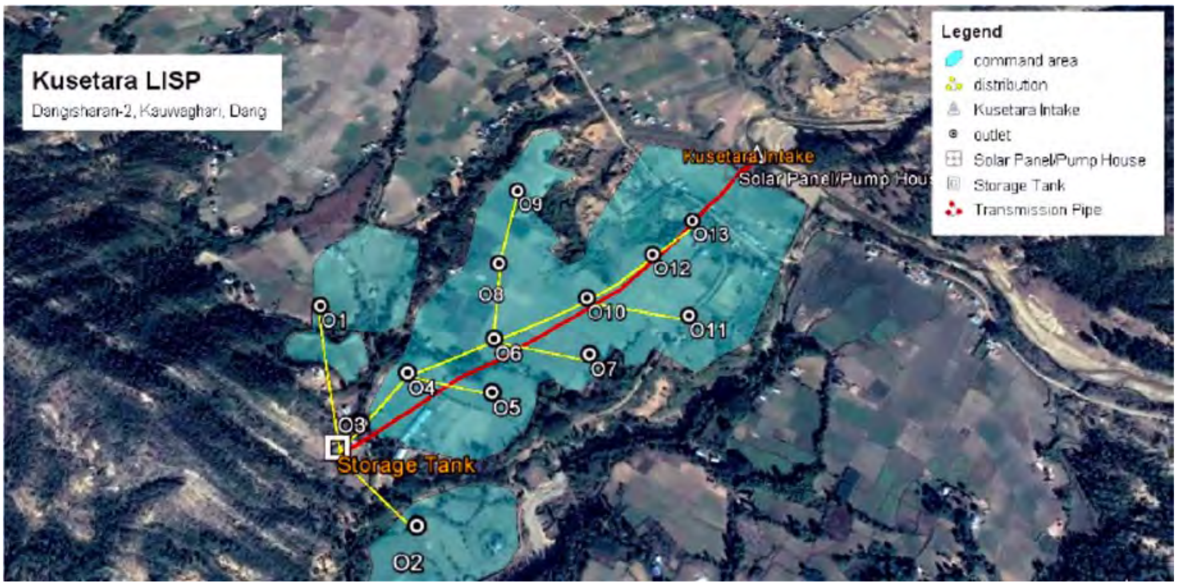
Annex 2-2 (d): Location and associated details of Naumure Dam (Rapti-Kapilbastu Diversion) Project (Source: IMP, 2019)

Annex 2-2 (e): Location and associated details of Bheri-Corridor Solar Lift Project (Source: IMP, 2019)

Notes: VDC is village development committee.



Annex 2-2 (f): Location and associated details of Bheri-Ghatgaon II Solar Lift Irrigation Project (Source: IMP, 2019)



Annex 2-2 (g): Location and associated details of Kusetara Solar Lift Irrigation Project (Source: IMP, 2019)

Note: LISP: Lift Irrigation Solar Project

Annex 2-3: Synthesis of literatures related to water resources and water infrastructure development in the Feed the Future Zone of Influence region, Western Nepal.

SN	Reference	Focus	Target area	Data/information that can be extracted	Key findings relevant to water resources and water infrastructure development
1.	Bhatta, et al. (2020)	Impact of past and future climate scenarios on Streamflow in a West Seti River Basin.	West Seti River Basin.	Future discharge annually and monthly.	Discharge is projected to increase by 16.4% (NF), 19.9% (MF), 18.3% (FF) under RCP 8.5. Pre -monsoon river discharge could increase by 12.4% (NF), 37.5% (MF), 65.5% (FF) under RCP 8.5.
2.	Dahal et al. (2020)	Future impacts of climate change on water availability in the Karnali River Basin.	Karnali River Basin	Current and future water availability of Karnali basin.	Current discharge at Chisapani is 43,362 MCM which is projected to Increase by 6.4 % (5.1 %) in MF and by 8.4 % (10.9%) in FF under RCP 4.5 (RCP 8.5). More water will be available especially during the pre-monsoon and monsoon seasons, and this scenario is likely to increase in the late century.
3.	Pandey et al. (2020a)	To developed a SWAT hydrological model using multi-site calibration approach to characterize present spatio-temporal distribution of water availability.	Karnali Mohona Basin	Present spatio-temporal water availability and assessment of water balance component (precipitation, ET, NWY).	Average annual flow volume at the Karnali-mohana basin outlet is 46,250 MCM. About 34 % of average annual precipitation in this basin is lost as evapotranspiration, but with a large spatio-temporal heterogeneity. The Hills and Tarai are relatively wetter than the Mountains.
4.	Pandey et al. (2020b)	To project future climate and assess impacts of climate change on water availability	Karnali Mohona Basin	Future spatio-temporal water availability at Karnali Mohana basin and also at its sub basin Bheri, Seti, Tila, Upper Karnali under RCP 4.5 and RCP 8.5.	The impacts in the sub-basins at higher altitudes are relatively higher, indicating higher vulnerability to CC of the high mountain regions of the basin than the flat lands in Tarai. For instance, in NF under RCP4.5 scenarios, the annual flow volume at the outlet of Tila is projected to change by -21.6 %, Seti by +13.9 %, upper Karnali by -7.2%, Bheri by -5.4 %, and Karnali-main by 0.6 %.
5.	WRPPF/DWRI (2020a)	Feasibility and detail study of flood preventing measure in proposed six basins to prepare priority river basins for flood risk management	West Rapti, Mawa-Ratuwa, Lakhandei, Mohana-Khutiya, East Rapti, and Bakraha watershed.	Proposed embankment, revetment length, number of spur, proposed number of rain gauge and hydrometric station in West Rapti and Mohana Khutiya watershed.	The Terai region has only 17% of Nepal's total land area but accounts for 51% of the 2.64 million hectares (ha) of cultivable land. During heavy monsoon rainfall in August 2017, the southern Terai plains were critically affected, with damage of almost 3% of Nepal's gross domestic product.
6.	WRPPF/DWRI (2020b)	Assess economic and financial viability for civil work, Flood Forecasting and Early Warning Systems (FFEWS), Community Based Disaster risk Management (CBDRM), Cost-Benefits Analysis (CBA) and assessment of social and environmental safeguards in West Rapti basin.	West Rapti	Existing and proposed rain gauge and hydrometric station in basin and LULC and geological map.	Agriculture account only for 20.3% in whole of the West Rapti Basin. 25 existing and 5 proposed raingauge station. 8 proposed hydrometric gauging stations in West Rapti, 5 stations will be used for both discharge and water level measurements and 3 stations will only measure water levels.
7.	WRPPF/DWRI (2020c)	Develop a flood forecasting and early warning system (FFEWS) in Mohana-Khutiya basin	Mohana-Khutiya basin	Existing and proposed rain gauge and hydrometric station in basin	History of 31 flood events (30 in Mohana and 1 in Khutiya) between 1991 and 2015. 6 existing and 11 proposed raingauge station in the basin. 2 existing and 9 proposed hydrometric station (5 are for water level and 4 for water level and discharge both).
8.	WRPPF/DWRI (2020d)	Detailed engineering design for flood prevention measures, including design of civil work and Bill of Quantities (BoQ).	Mohana-Khutiya basin	LULC, Geology map of Mohana Khutiya basin.	90 % of the total area of the basin upper catchment has dominant non-agricultural land use types such as forest, shrub and grass. This indicates the ecology is least disturbed. However, the deforestation and the overgrazing on the steep areas could induce erosion. The lower catchment has dominant agricultural land use and built-up areas comprising 55% of the total area.
9.	Bhattarai & Shakya (2019)	Conjunctive use of water resources in sustainable development of agriculture in Terai Nepal	Terai Nepal	Information on conjunctive use by different country and its significance and the different model used by different author for conjunctive uses	At present, 42% of the cultivated area has irrigation of some sort, but only 17% of cultivated area has year-round irrigation.
10.	Bhattarai et al. (2019)	To prepare inundation map of a section of Babai Basin and to find out the inundated areas for different return periods.	Babai basin: Near about 40 km south of Babai Bridge in Ratna Rajmarga near Purandhara, Dang.	Inundation Maps for different return periods. Flooded area according to land use vulnerability under different return period.	Flood water depth shows that all of the areas under flooding have water depth less than 18 m. large percentage (47 to 49%) of vulnerable area is agricultural land and followed by water body (38 to 46%) and forest (3 to 10%).
11.	DJB (2019)	Final report: Sustainable, productive water resources development in Western Nepal under current and future conditions.	Karnali, Mahakali and Mohana basin	Biophysical characteristics, institutional and policy landscapes, social systems and gender, water sources and access, environmental flow requirements, and trade-offs and synergies among potential future development pathways.	For Karnali-Mohana basin, despite the seasonal and spatial heterogeneity, there is high water availability and high potential for water resources development. High-risk scenarios with drier and warmer climates are more likely to occur in the Tarai plains than in the mountains. The hills and plains will see the highest fluctuation in precipitation while the mountains will see the highest increases in temperature. For Chamelia, a major tributary of Mahakali on the Nepalese side, water availability under future climate is also projected to increase gradually from the baseline to near, mid and far-futures.

Annex 2-3: Synthesis of literatures related to ... cont'd.

SN	Reference	Focus	Target area	Data/information that can be extracted	Key findings relevant to water resources and water infrastructure development
12.	IMP (2019)	Irrigation Master Plan of Nepal	Nepal	Surface water availability of all major basin of Nepal (Karnali, Narayani, Koshi) and for its sub basin in spatial map. Groundwater recharge in Bhabar, Seepage and Terai Zone across FtF district. Surface and groundwater development project for irrigation as well as hydropower development across FtF zone along with problem, constraints, way forward in irrigation development of Nepal.	Annual surface water resources of Karnali basin is 60 BCM. Total annual groundwater resources of Karnali basin is about 3.4 BCM. Groundwater recharge (MCM) of Terai FtF district in Kapilbastu: 692, Dang: 324 , Banke: 632, Bardia: 759 Kailali: 864, Kanchanpur: 789. Surface and groundwater project scenario in Karnali basin are Bheri Babai transfer, Karnali transfer, Madi Dang diversion, Naumure dam and Under construction project are Mahakali Stage 3, Sikta Irrigation Project, Rani-Jamarya-Kulariya Project, Mega Dang Valley, Bheri-Babai Diversion Multipurpose.
13.	Nepal et al (2019)	Investigates water security in Nepal from the perspective of the water-energy-agriculture (food) nexus, focusing on pathways to water security that originate in actions and policies related to other sectors.	Terai Basin	Major issues and Water security measures in Agriculture, Domestic, Hydropower, Industry, Environment sectors.	Water security measure in Agriculture are: Increasing water supply through infrastructure and rejuvenation of springs, Groundwater pumping using grid electricity and off-grid solar power, Small and local-scale water storage and rainwater harvesting, Inter-basin water transfer, Irrigation technologies, farming technologies demand management, Formal and informal water markets.
14.	Neupane et al. (2019)	Study of river channel migration and identification of potential sugarcane cultivation area in the Mohana –Macheli watershed	Mohana-Macheli	Sand area change in Mohana-Macheli Watershed from 2009 to 2017	There is maximum erosion form 2009-2011 at that time of no mitigation measures. Total land erosion after mitigation was found to be decrease by 71% during the year 2009 to 2017. Highest shift in channel is seen in Dodha River where the channel has shifted to as high as 1000 meters from the original path. The channel migration of various rivers has directly affected the land use and flood plain settlements of the area. This study shows the cultivation of sugarcane in river bank can protect the lateral shift of river.
15.	PMAMP (2019a)	Third PMAMP quarterly annual progress report of fiscal year 2075/76.	Across Nepal covered all Terai FtF district.	Running PMAMP project in Fiscal year 2075/76 (July 2018-july 2019), Zone added for fiscal year 2076/77 (July 2019-july 2020).	Running PMAMP project of fiscal year 2075/76 in Terai FtF Zol are: Dang (Mustard), Kapilbastu (paddy, Vegetable); Banke (maize), Kanchanpur (Paddy) for Zone project and Dang (maize), Kapilbastu (Paddy), Bardia (Paddy), Kailali (wheat) for super zone project.
16.	PMAMP (2019b)	Annual programme and progress report of PMAMP (FY 2075/76), 2019	Across Nepal covered all Terai FtF district.	Agricultural production under Pocket, block, Zone, Super Zone project of Terai FtF district in FY-2074/75 (july 2017-july 2018). Agricultural production under combine super zone and zone of 6 district of year (2074/75)- (July 2017-july 2018) and (2075/76-July 2018/july 2019) Number of solar and small irrigation infrastructure in Terai FtF district.	Zone implementation in FY 2074/75: Kanchanpur (Paddy), Kailali (Oilseed), Bardia (Paddy), Banke (Maize). Proposed Zone in FY 2075/76: Kanchanpur (Paddy), Banke (Maize), Dang (Mustard and Bee farming), Kapilbastu (Vegetable and Fish). Superzone implementation in FY 2074/75: Kailali (Wheat), Dang (Maize). Proposed Superzone in FY 2075/76: Kailali (Wheat), Bardia (Paddy), Dang (Maize), Kapilbastu (Paddy).
17.	Pandey et al. (2019)	Current and future hydrological system of Chamelia using SWAT.	Chamelia watershed	Current and future spatio-temporal water availability and water balance component of Chamelia watershed and water balance.	Average annual current discharge at outlet of basin is 2,081 MCM which is projected to increase gradually from the near to far future under both RCPs; for instance, by 8.2% in near, 12.2% in mid, and 15.0% in far-future under RCP4.5 scenarios.
18.	Pakhtigian et al. (2019)	To maximize the total economic benefit within the KarnaliMohana and Mahakali River basins, from four water-related sectors: (i) energy, (ii) agriculture, (iii) municipal, and (iv) environmental sectors.	KarnaliMohana and Mahakali River basins,	Source and methodology for irrigation and municipal water demand estimation.	Surface water availability is generally sufficient to meet existing and growing demands in energy and agricultural sectors however, expansion of water storage and irrigation infrastructure may limit environmental flows below levels needed to maintain the full integrity of important aquatic ecosystems. Substantial trade-offs between irrigation in Nepal and satisfaction of the institutional requirements implied by international water-use agreements with the downstream riparian India.
19.	Talchabhadel et al. (2019)	Assesses the projected impacts of climate change on rainfall erosivity (R-factor) in west rapti basin	West Rapti	Mean annual soil erosion for historical, future scenarios in different elevation band of west Rapti basin.	Annual R-factors are expected to increase by 10% in the higher region, and 16.7% in the lower region of West Rapti during 80's under RCP 8.5. Results show a slightly greater increment under RCP 4.5 than RCP 8.5. Increase in rainfall intensity and erosion of soil can significantly affect the agriculture.

Annex 2-3: Synthesis of literatures related to ... cont'd.

SN	Reference	Focus	Target area	Data/information that can be extracted	Key findings relevant to water resources and water infrastructure development
20.	Bista et al. (2018)	To investigate the impact of climate change in Western Mountainous Water Basin.	Western Basin	Review on Impact of climate change in western mountain water basin at global level, national level, local level.	Over the last 36 years (1975-2010) in western Nepal, temperature is rising on an average of 1.2°C per annum. This is twice as compared to the global increment. This indicates more vulnerability of climate change in hills and high hills of Nepal. The average rise of temperature in Nepal is 0.06 °C per year.
21.	DWSSM (2018)	Water supply and sanitation status in Nepal	Nepal	Water supply and sanitation coverage across Province and in general across district, Palika of 2018.	The water supply coverage of province 5 is 88.57% which was 82.8% as per report of 2010. In this province high water supply coverage found in Rupandehi of 98.6% and minimum coverage found in Dang of 75.56%. The water supply coverage of province 7 is 86.53% which was 83.31% in 2010 which seems to be slow in respect to other province. Less water coverage found in Kanchanpur about 73.7% and maximum coverage found in Kailali 96.61 %.In context of district all Terai FtF district has sanitation coverage except Kapilbastu, which has coverage of 99.42%.
22.	DOA (2018)	Inter provincial dependency for agricultural development.	All province of Nepal	Provincial strength, weakness, opportunities and threat regarding agriculture development.	In province 5 there is availability of large fertile lands, suitable for all kinds of cereals crops but having low year round irrigation facility, prevalence of single crops in many Terai area mostly rice and low level of processing units. In province 7, there is presence of both Terai and Hills region and many donors funded projects. But still disconnected with country capital and getting low priority in development works, having poor connectivity in hills and high hills district and lack of market infrastructures for value chain development.
23.	Dhami et al. (2018)	To test its applicability for hydrological simulation and carry out the water balance of the basin and to determine the snowmelt contribution in the river flow.	Karnali River Basin	Current water availability at Karnali basin outlet and contribution to snowmelt.	Average annual runoff volume available at the basin outlet is about 47,160 MCM out of which about 12% of runof volume is contributed by the snowmelt runof. About 25% of annual precipitation seems to be lost as evapotranspiration.
24.	IMP (2018)	Irrigation water use inventory final report to prepare a spatial database of all irrigation schemes of Nepal.	Nepal	Shallow tubewell and irrigated area up-to 2073/74; Deep tubewell and irrigated area up-to 2073/74	About 40,939 number of shallow tubewell and 454 number of deep tubewell exist in the Terai FtF district. About 85% of irrigation is by shallow tubewell.
25.	Mishra et al. (2018)	Effects of climate change on streamflow in the Bheri River using SWAT.	Bheri	Current and future annual and temporal water availability of Bheri basin	Average annual discharge of Bheri at Jammu station is 13,087 MCM which is projected to Increase by 6–12.5% by the end of century. On a monthly scale, runoff will decrease in July and August by up to 20% and increase in the dry period by up to 70%, which is favorable for water users.
26.	Panthi et al. (2018)	Water Poverty Index (WPI) indicators to encompass the climatic extremes and social settings to analyze the water stresses to the community people and their capacity to manage the water extremes focusing on the water availability in climatic variability condition.	Humla, Kalikot and Kailali district of Karnali & Mohana basin.	Water poverty status of these districts. Reason of water poverty in term of 5 major WPI component (Resource, access, capacity, use, climate change and environment).	WPI is highest in Kalikot followed by Humla district and lowest in Kailali district. Major factors pushing high water poverty in Kalikot are climatic and environmental change, water availability and reliability and people capacity to manage the available water resources. Water poverty is least in Kailali due to availability of personal water pumps in each of the household's area and having irrigated lands, but it has least value on environment and climate change due to higher number of flood frequency and drought incidence.
27.	Pathak (2018)	Evaluate the present situation of the existing groundwater exploitation in the entire Terai and Inner Terai, Nepal.	Terai and Inner Terai, Nepal.	Number, depth, groundwater yield of deep tubewell across Terai FtF district.	The deep wells in Dang districts have been exploiting the deepest aquifers (<250 m deep), while the wells in other district exploits aquifer from depth below 200m to 140 m. Minimum average exploiting aquifer depth found in Kanchanpur district followed by Bardia district. It is observed that the aquifer in Bardia district (32 liter per second- lps) followed by Kanchanpur (28 lps) having comparatively high yield and productive while Dang district shows less productive with average yield less than 15 lps. Wells between 50 and 75 m deep has the lowest yield while it gradually increases for the well between 175 and 200 m deep.
28.	Shrestha et al. (2018)	Overview on Groundwater resource of Nepal	Nepal	District wise graph of water level in shallow & deep aquifer below ground level. Geological section of Banke & Bardia, Transmissivity of shallow aquifer, District wise groundwater arsenic concentration.	Deepest water level of 16.5 m bgl was found at the Dang district among 20 Terai district of Nepal. Maximum transmissivity value of the shallow aquifer found in Dang i.e 10,000 m^2/day among Terai FTF district. In Kailali and Bardia more than 20% of tube well (TW) and in other Terai FTF district 4-15% of TW have arsenic concentration above 10 ppb. Maximum % of arsenic concentration above 50 ppb found in kailali district among Terai FTF district.
29.	Tripathee (2018)	To analyse climate change impacts on water resources and crop yield in Mohana River Basin	Mohana	Current and future spatio-temporal water availability in Mohana basin.	Baseline average annual discharge 4793 MCM which is projected to increase by 16% (24%), 4% (14%) and 17% (18%) in near, mid and far future under RCP 4.5 (RCP 8.5).

Annex 2-3: Synthesis of literatures related to ... cont'd.

SN	Reference	Focus	Target area	Data/information that can be extracted	Key findings relevant to water resources and water infrastructure development
30.	PAANI (2017)	Assesses the status, major challenges and opportunities facing water resources management for the multiple users located within the Lower Mahakali Watershed	Lower Mahakali	Source of drinking, irrigation uses survey; List of Irrigation Projects in Lower Mahakali Watershed; Summary of prioritized issues by Municipality.	Lack of proper transboundary water management with India has caused impact on agriculture during both monsoon and winter season also e-flow criteria is below the minimum requirement. Frequency of high intensity rainfall events is increasing, particularly during the mid-monsoon period, while the yearly average of precipitation is decreasing at a rate of rate of 10 mm/year. Frequent flood events have caused losses to human life and physical assets, including the loss of livestock and agricultural land through erosion and logged irrigation system by sedimentation. The study shows lack of downscaled climate change projections for the Mahakali River Basin, in addition, there are knowledge gaps in terms of the impact of irrigation systems (current and planned) on freshwater biodiversity as well as the impact of increased sedimentation on the functioning of the irrigation systems.
31.	Shrestha (2017)	To assess uncertainty in streamflow estimates for a mountainous basin of regional scale in Nepal by uncertainty of climate change projections originating from a selection of downscaled Regional Climate Models (RCMs).	West Rapti	Climate change impact on streamflow, precipitation, temperature.	Increment range from 2.6 m^3/s to 8.1 m^3/s for RCP 4.5 and from 8.8 m^3/s to 44.8 m^3/s for RCP 8.5.
32.	Thapa et al. (2017)	Combined land cover changes and habitat occupancy to understand corridor status of Laljhadi-Mohana wildlife corridor(LMBC), Nepal	Mohana	Land cover of LMBC (2002–2012) and changed in land cover attributes	Dense forest area was reduced by 18.35% in a decade while cultivation and sparse forest increased by 10.15% and 8.89%, respectively. Illegal forest encroachment, resource extraction, grazing pressure, invasive species, and flood were major drivers of forest change
33.	Khatiwada et al. (2016)	Overview of hydro-climatic parameters that have been observed during 1981–2012.	Karnali	Spatial and temporal variability of temperature and precipitation	Average precipitation shows decreasing trend by 4.91 mm/year i.e. around 10% during the year 1981-2012. Increase rate of maximum temperature is 0.05 °C/year and minimum temperature is 0.01 °C/year. Although the annual precipitation in most of the stations shows a decreasing trend, there is constant river discharge during the period 1981–2010. This basin is mostly susceptible to drought and higher food prices, it will take longer for households in this region to recover from climatic shocks
34.	WRPPF (2016)	Pre-Feasibility Study Report of Mid-Hill Lift Irrigation Project (Package-6)	Palpa, Syangja, Tanahun, Lamjung and Gorkha Districts	This report shows the importance of lift irrigation in mid-hill area of Nepal. Short introduction with command area of existing lift irrigation in FtF district and command area of proposed lift irrigation in Palpa district.	Potential command area by proposed planned lift irrigation in Palpa district is about 586 ha.
35.	Bohara (2015)	Physico-chemical and microbiological analysis of drinking water quality of Bhim Datta Muncipality	Bhim Datta municipality (Mahendranagar) headquarters of the Kanchanpur district.	Result of physicochemical parameter of drinking water, bacterial contamination in different source of GW in drinking water.	Physico-chemical analysis of water samples were within national standard and WHO guideline. However, arsenic total hardness, total alkalinity, ammonia, Chloride, Nitrate were not in satisfactory level. Although high contamination in Hand pump and Tubewell water, many households of Bhim Datta Municipality have to resort to hand pumps because of poor reliability and services of piped water.
36.	Gurung et al (2015)	Drinking water quality parameters from groundwater source	Bhajani and Chuha VDCs of Kailali district.	Result of groundwater water quality	Most of the parameters such as colour, pH, turbidity, TDS, electrical conductivity and total hardness were within the prescribed limit. Some heavy metals such as Al, Pb, Cd, Fe, As and Mn exceeded in some of the samples indicating possible risk to the community.
37.	Hengaju & Manandhar (2015)	Analysis on causes of deforestation and forest degradation of Dang district using Drivers – Pressures – State – Impacts – Responses (DPSIR) framework.	Six representative VDCs of Dang District: Rajpur, Bela, Satbariya, Gobardiya, Gorahi Municipality and Saidha VDC.	Data and information on causes of deforestation and forest degradation in Dang district.	Main causes of deforestation & forest degradation in Dang District are forest encroachment, population growth, forest fire, urbanization, infrastructure development, illegal harvesting of forest resources; In order to overcome with the situation, government, with an effort from community people has started awareness programs and many other activities under forest management programs.
38.	Perera et al. (2015)	Community-based flood damage assessment approach for lower West Rapti River basin under the impact of climate change	Matehiya, Gangapur, Holiya, Bethani, Phattepur VDC of Banke district.	Household and agricultural flood damage assessment.	Future flood frequencies, intensities, and consequent damages in the area show a significant increment compared to the present situation. Total increment of household and agriculture flood damages due to climate change for present (2011) is 1.8 and 1.95 NRs billion and for future (2099) is 2.4 and 2.77 NRs billion. VDCs located in lower part are quite vulnerable in terms of floods, and they are categorized as mostly affected.

Annex 2-3: Synthesis of literatures related to ... cont'd.

SN	Reference	Focus	Target area	Data/information that can be extracted	Key findings relevant to water resources and water infrastructure development
39.	Adhikari et al. (2014)	To determine threshold value of discharge and water level for flood warning and danger levels at forecasting stations of Mohana and Macheli River basin for the purpose of developing threshold-stage based operational flood early warning system	Mohana and Macheli River basin	Warning and danger level Inundation map of Mohana and Macheli River system and tributaries. Number of settlements likely to be effected under inundation area at Danger level of Flooding in Mohana and Macheli River and tributaries.	Lower basin of mohana has high risk of flood. The depth of inundation is around 5 m. The warning level is considered for inundation scenario of return period at which the water level reach to bank full stage or nearer to bank full stage. For Danger level, surface water level at 1m above the bank full stage is considered.
40.	Bhandari (2014)	To explore the relationship between rainfall and yield of major cereals in Darchula district of Nepal.	Darchula District	Relationship between rainfall and yield of major crop.	In the years 1976, 1977, 1999 and 2000, the decrease in the amount of rainfall has reduced the yield of all major cereals in Darchula district of Nepal.
41.	NMIP (2014)	Nationwide coverage and functionality status of water supply and sanitation in Nepal	All district of Nepal	Water supply and sanitation coverage, number of water supply scheme and type of water source across district upto 2014 and also available for 2010 and 2012.	Least water supply coverage found in Dang district (73%) but have 100% coverage of sanitation. Least sanitation coverage found in Kapilbastu (57%) followed by Banke (60%).
42.	Bhandari (2013)	This study examines the effect of precipitation and temperature variation on the yield of major cereals (e.g., rice, wheat, maize, millet and barley) in Dadeldhura district	Dadeldhura	Relationship between rainfall and temperature with yield of major crop.	1979, 1980, 1982 and 1987 are the major agriculture drought years in Dadeldhura district of far western development region, Nepal. maximum temperature and minimum precipitation have had adverse effects on the yield of rice and maize.
43.	Gurung et al. (2013)	Application of the SWAT Model to assess climate change impacts on water balances and crop yields in the West Seti River Basin.	West seti	Impact of climate change on yield of major crop i.e rice, maize, millet, wheat, barley.	Yield of rice, maize and millet will decrease by 10%, 7.9% and 26.1% whereas yield of wheat and barley will increase by 7.8% and 5.8% respectively depending on precipitation and ET by end of NF; Therefore, the impact of climate change shows that summer crop yields will decrease and winter crop yields will increase.
44.	Wang et al. (2013)	Causes of winter drought in western Nepal during recent Years.	Western Nepal	Winter drought condition in western Nepal and its causes.	Western Nepal has experienced consecutive and worsening winter drought conditions since 2000, culminating in a severe drought episode during 2008/09 due to increased loading of anthropogenic aerosols declining precipitation. Winter precipitation has declined to near zero while groundwater has hardly been replenished, appropriate management of western Nepal's water resources is both critical and necessary.
45.	Pandey et al. (2012)	This study uses Water Poverty Index (WPI) framework to assess water poverty situation of medium-sized river basins in Nepal.	Medium-sized river basins (West Rapti, Babai, Bagmati, Kamala and Kankai)	Water poverty status of medium river basin of Nepal and the reason behind the water poverty. Prioritize order of component of water poverty index responsible for water poverty.	Highest water poverty found in West Rapti then Babai, Bagmati, Kamala, Kamkai. The decreasing order of priority of WPI component in West Rapti is: Use>Environment>Capacity>Resources >Access and in Babai is: Use>Capacity> Resources>Access>Environment. In case of West Rapti Basin, the domestic use and irrigation uses is lowest among medium 5 basin. In case of Babai, water supply and sanitation and its reliability is lowest and high amount of fertilizer and vegetative coverage are being used.
46.	Siddique et al. (2012)	Climate Change and Vulnerability Mapping in Watersheds in Middle and High Mountains, of Nepal	Midddle & high mountain watershed of Nepal	Watersheds ranked by combined/multiple vulnerability index including district name within watershed. Watersheds ranked by state of vulnerability in large and medium river basin of Nepal.	Karnali basin are more vulnerable among all Nepal basin of which upper sub basin watershed of Karnali basin are more vulnerable.
47.	Yadav et al. (2012)	Arsenic (As) contamination in drinking water	Sunsari, Dhanusha, Bara, Rupandehi, Kailali, and Kanchanpur district.	Geographic distribution of Arsenic concentrations; Distribution of Arsenic by depth of Tubewell.	Kailali having the highest mean Arsenic concentration (6.27 mg/l), followed by Kanchanpur (4.98 mg/l). Tubewells having a depth less than 20-m had average higher arsenic concentrations and deeper tubewells contained lower average arsenic concentrations.
48.	WECS (2011)	Status of Water Resources in Nepal	All major large and medium basin of Nepal.	Status of Water Resources in Nepal. Estimated runoff from the rivers of Nepal based on data of WECS, 2003, Water uses of Nepal, Specific discharge of large and medium Nepal basin.	Estimated Runoff (m^3/sec) from Nepal in Mahakali is 247, Karnali is 1371, Babai is 103, West Rapti is 224.
49.	Pandey et al. (2010)	Vulnerability of freshwater resources in large and medium Nepalese river basins to environmental change	Large basin (Karnali, Narayani, Koshi) and medium-sized river basins (West Rapti, Babai, Bagmati, Kamala and Kankai)	Irrigation, domestic water use, waste water of these all basin. Vulnerability status and rank of basins.	Nepalese river basins are ranked in decreasing order of vulnerability as - Babai, Kamala, Karnali, Bagmati, West Rapti, Kankai, Mahakali, Koshi and the Gandaki. Babai is the most vulnerable medium basin due to poor water resources management followed by ecological insecurity and is less related to resources stress whereas west Rapti basin indicate for water stress. The water use percentage from available water resources in Babai is 77%, West Rapti is 12%, Karnali is 7% and Mahakali is 3%.

Annex 2-3: Synthesis of literatures related to ... cont'd.

SN	Reference	Focus	Target area	Data/information that can be extracted	Key findings relevant to water resources and water infrastructure development
50.	Adhikari et al. (2009)	To find a strategy to provide year-round irrigation for cultivating three crops per year in the southern plains of the country taking a case study of the Babai basin.	At the right and left banks of the Babai river in Bardiya	Status of irrigation system of Babai basin; source of irrigation; Evapotranspiration; Monthly water balance scenario for irrigation from Babai river; Monthly water withdrawals from the Karnali river for irrigation; Water requirement and deficit scenario at various cropping intensities; Water surpluses and deficit at different regions during the dry season.	Despite having enough flows during the summer for growing rice in total 27,000 ha area, the dry season flows of the Babai river can irrigate only 6,300 ha in winter and 4,000 ha in spring limiting the cropping intensity to 138.50%. Water balance study of the three irrigation regions to be irrigated from the Babai source showed that the year-round irrigation at the west with the proposed arrangement will fall short of only 13.9 MCM water volume. At the east side, the head reach area and the tail portion will fall short of 19.4 and 66.4 MCM of water to insure a cropping intensity of 250%. The deficits can be fulfilled by means of capturing the excess river water of rainy season in local reservoirs and by making conjunctive use of groundwater.
51.	Mahat & shrestha (2008)	To visualize the scenario of metal contamination in ground water.	Dang District	Result of contamination of Arsenic, Iron, Copper, Manganese , Cadmium of sample tube well.	Of the total samples, 50.3% was found to contain arsenic above WHO drinking water quality guidelines value of 10 ppb and 10.7% sample was found to contain arsenic above national drinking water quality guidelines value of 50 ppb. Safest VDC is Sonpur while the most severely affected VDC is Gobardiha. Highest concentration of Arsenic of 240 ppb was found in Dhikpur VDC. Ground water in this area seemed to be affected by high concentration of iron up to 11.01 mg/l and of manganese up to 0.51 mg/L.
52.	Sapkota (2003)	Hydrogeological conditions in the southern part of Dang valley.	Dang Valley: Study area stretches from below the Ghorahi-Tulsipur highway in the north down to the Babai River in the south	Thickness of permeable, semi-permeable and impermeable layers in STW, DTW, Dugwells. Detail on Hydrogeological characteristics of deep and shallow aquifers. Aquifer characteristic description	Annual domestic water draft and groundwater safe yield were calculated to be 7.43 x106 m^3/year and 3.16 x 107 m^3/year, respectively. Safe yield is higher than the annual draft (i.e by 49%) indicates the presence of good groundwater potential in the study area. Most of the lithologs of the wells reveal the permeable material to be greater than 40%. Northern portion of the study area has more permeable surfaces than the southern and central portions.
53.	Water resource strategy (2002)	To determine a path involving medium- and long-term action programs for resolving conflicts and achieving water-related development objectives.	Large and medium river basin of Nepal.	Summary of Nepal basin Water Balance	Water balance status for present (2000) and future 2027 in large and medium basin as: In Mahakali present and future water needs can be comfortably met, in Karnali water surpluses offer opportunities for large multipurpose benefits, in Babai water shortage exist, however if diversion from Karnali Basin (Bheri) is undertaken a large water surplus is available, in West Rapti water supply will be adequate to support some surface irrigation.
54.	Yadav (2002)	To investigate the effect of flow regimes and river water temperature regime on aquatic ecology downstream from the intake site in Bheri river and downstream from the outlet in Babai river after diversion of 40 m^3/s of discharge from Bheri to Babai river.	Bher Babai basin	General introduction of hydrology Bheri and Babai basin; Effect of flow regimes and river water temperature regime on aquatic ecology downstream from the intake site in Bheri river and downstream from the outlet in Babai river after diversion of 40 m3 /s of discharge from Bheri to Babai river.	The temperature of mixed water at Chepang (outlet) during this period would range between 22.2 °C and 26.1 °C, which is within the range of temperature tolerance to aquatic flora and fauna. Temperature differences of mixed water from Bheri outlet and Babai River range from 0.9 °C in July to 3.2 °C in May. The highest temperature difference is in the months of April, May and June (2.2 –3.2 °C) because these are the months when the river has low flows (9-46 m^3/s). The temperature difference after mixing of Bheri River with Babai would gradually decrease with distance.

Notes: DoA – Department of Agriculture; WRPPF – Water Resources Project Preparatory Facility; PMAMP - Prime Minister Agriculture Modernization Project; ET: Evapotranspiration, NWY: Net water yield; SWAT: Soil and Water Assessment; NF: Near future; MF: Mid future; FF: Far future; MCM: Million Cubic Meter; BCM: Billion Cubic Meter; bgl: Below groundwater level; ppb: part per billion; STW: Shallow Tubewell; DTW: Deep Tubewell; VDC: Village Development Committee; mg/l: Milligram per liter; TDS: Total Dissolved Solids. Province 5 is already renamed as Lumbini Province.

Notes:

Notes:

International Maize and Wheat Improvement Center (CIMMYT)
CIMMYT- Bangladesh. House 10/B. Road 53. Gulshan-2. Dhaka, 1213, Bangladesh

Funded by

Partners