Climate Adaptation and Resilience (CARE) for South Asia Project

Water Harvesting: A Needs Assessment for Nepal

ASSESSMENT REPORT

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1. INTRODUCTION

The Asian Disaster Preparedness Center (ADPC) and the Regional Integrated Multi-Hazard Early Warning System (RIMES) are jointly implementing a five-year (2020-2025) regional project called 'Climate Adaptation and Resilience (CARE) for South Asia with support from the World Bank. The overall objective of the project is to contribute to an enabling environment for climate resilience policies and investments in agriculture, transport, water, and policy & planning, and finance sectors in South Asia. Initially, the national-level activities are being implemented in Bangladesh, Nepal and Pakistan.

The project has two parallel but distinct components: RIMES is implementing the first component which focuses on promoting evidence-based climate smart decision-making; ADPC is implementing the second component which focuses on enhancing policies, standards, and capacities for climate-resilient development in South Asia. ADPC is looking specifically into 1) Advisory services for policy and investment interventions; 2) Promoting climate resilient design and standards; and 3) Implementation support to climate-risk management solutions: capacity building and technical support.

Climate change impacts in Nepal, as well as around the globe, primarily manifest through water; changes in the precipitation pattern alter the availability of water (Pörtner, et al., 2022). Impacts can be on the frequency as well as the intensity of precipitation events (Chaturvedi, et al., 2022; Trenberth, 2011; MOFE, 2019), form of precipitation events, with changes ranging from snowfall to rainfall (Sharma and Goyal, 2020), delayed onset of the rainy season, or even extended periods of drought/ the period between successive rain events (Mondal et al., 2021; Pörtner, et al., 2022). While irrigated areas can be considered to be better positioned to adapt to these changes in precipitation, rain-fed agricultural lands or those that have limited water for irrigation are severely impacted.

Arable lands in arid and semi-arid regions with physical water scarcity (Molden, 2013; Yu et al., 2021) are more vulnerable to climate change. Even areas in the tropics or sub-tropics that have extreme seasonal variations in precipitation or have limited supplementary irrigation facilities can be exposed to hazards like drought impacting crop yield and production. The National Adaptation Plan of Nepal (GoN, 2021) also lists water stress and lower water availability during the winter season, causing water shortages in rural and urban areas, as a major climate risk that need to be addressed with priority. Climate change impacts coupled with other anthropogenic causes are believed to be responsible for the reduction in flow or even drying-up of springs in Nepal (Adhikari, et al., 2021; Shrestha et al., 2017) as well as in the Eastern Himalayas in Sikkim, India (Tambe et al., 2012) limiting water supply for domestic and agriculture purposes.

All of these highlight the need for adopting measures to assure the availability of water resources round the year by seeking to store or harvest water when it is available and release later when required. Increasing water security, especially in rural agrarian societies, is an apt strategy towards adaptation and building resilience in the battle against climate change, as highlighted in the Asian Water Development Outlook, 2020 (Panella et al., 2020). Water harvesting, including storage, strengthens water security which can further translate to food security, through irrigated agriculture and increased production, and energy security through the adoption of hydropower generation. Hydropower is a clean renewable energy which is expected to replace energy derived from fossil fuels and help in meeting nations' carbon reduction targets.

This report assesses the need for water harvesting in Nepal. Rainwater harvesting from rooftops and built-up areas are well-known and practiced methods of water harvesting and this report is geared more towards the medium to larger macro-catchment approaches of utilizing stream runoff and flood flows to address seasonal water scarcity by building up primarily surface storage, e.g., as depicted conceptually in Figure 1 This approach resonates with building resilience and adaptation to climate change. This study supports the objectives of the CARE for South Asia project in providing advisory services for policy towards building resilience and adapting to climate change in the water sector and adds to the policies and program initiatives of the Government of Nepal such as the Climate Change Policy (2019), the Nationally Determined Contribution (GoN, 2020), the National Water Resources Policy 2020 (MOEWRI, 2020), etc.

The document is expected to brief and guide future project interventions in the water sector in general and highlight the specific need to address seasonal water scarcity at the local watershed and macro-basin levels.

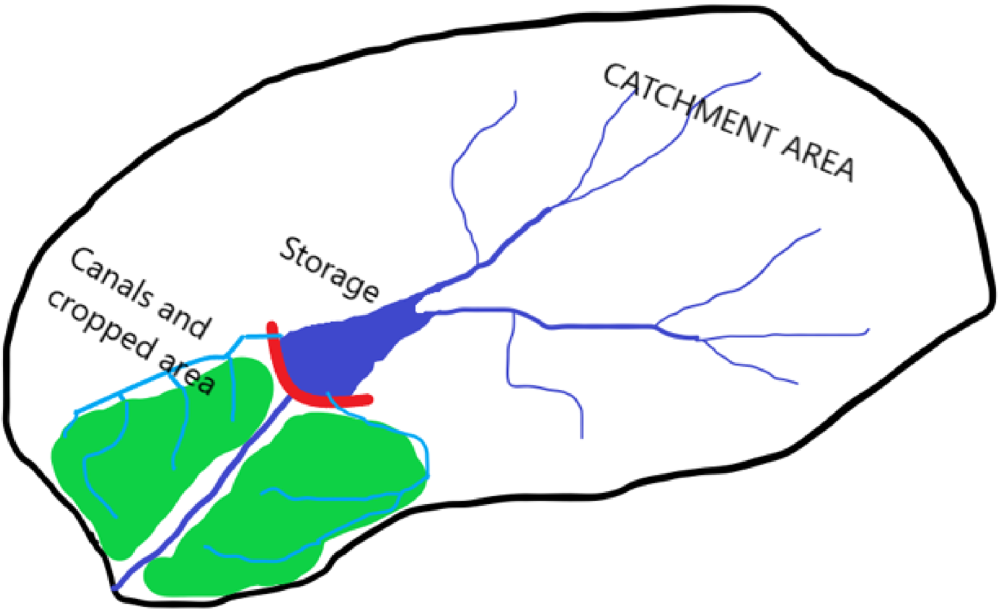


Figure 1: Components of a typical water harvesting system on a catchment basin for agricultural use

2. WATER HARVESTING

2.1 Introduction and definition

Water harvesting is a practice used to harvest or collect water and make it available for crops and other needs. It is an adaptation to water-stressed conditions (Mekdaschi-Studer and Liniger, 2013). This has been practiced since ancient times around the world to address water shortages for varied uses. Water harvesting is the concentration of rainfall and runoff from roofs, watersheds or built-up areas for beneficial use and is formally defined (Mekdaschi-Studer and Liniger, 2013; WOCAT, n.d.) as follows:

The collection and management of floodwater or rainwater runoff to increase water availability for domestic and agricultural use as well as ecosystem sustenance.

The above definition makes it clear that all forms of collecting rainwater, directly from rooftops and pavements to tanks or by redirecting runoff from catchment surfaces to ponds, lakes or reservoirs, or directly to concentrating run-off to field applications are all water harvesting practices. Therefore, water harvesting is a general term that encompasses rainwater harvesting as well as runoff or floodwater harvesting. harvesting.

The components of a water harvesting system include a catchment or collection area, a storage part and a distribution or abstraction system for the targeted use (Figure1). An additional conveyance system may also be required in larger systems. Water harvesting includes collecting runoff during times of excess and storing it on surface tanks, reservoirs or even in sub-surface aquifers or groundwater and abstracting it when required. This requires impeding, channeling and collecting surface runoff as well as increasing storage to make more water available for domestic, irrigation or use of livestock. The stored water will provide resilience against droughts or periods of no rain. It can, for example, provide a critical supply of water for planting seeds or raising seed beds in the dry months before the onset of monsoon in Nepal for paddy cultivation.

2.2 Types of Water Harvesting

It is necessary to understand the different types of water harvesting depending upon the purpose, source of water, storage methods and structures. Commonly understood types of water harvesting systems are listed below, while Figure 2 shows various storage systems;

1. Rainwater harvesting
2. Runoff water harvesting and/ or Floodwater harvesting
3. Subsurface dams; aquifer recharge, storage and recovery.
4. In-situ water harvesting

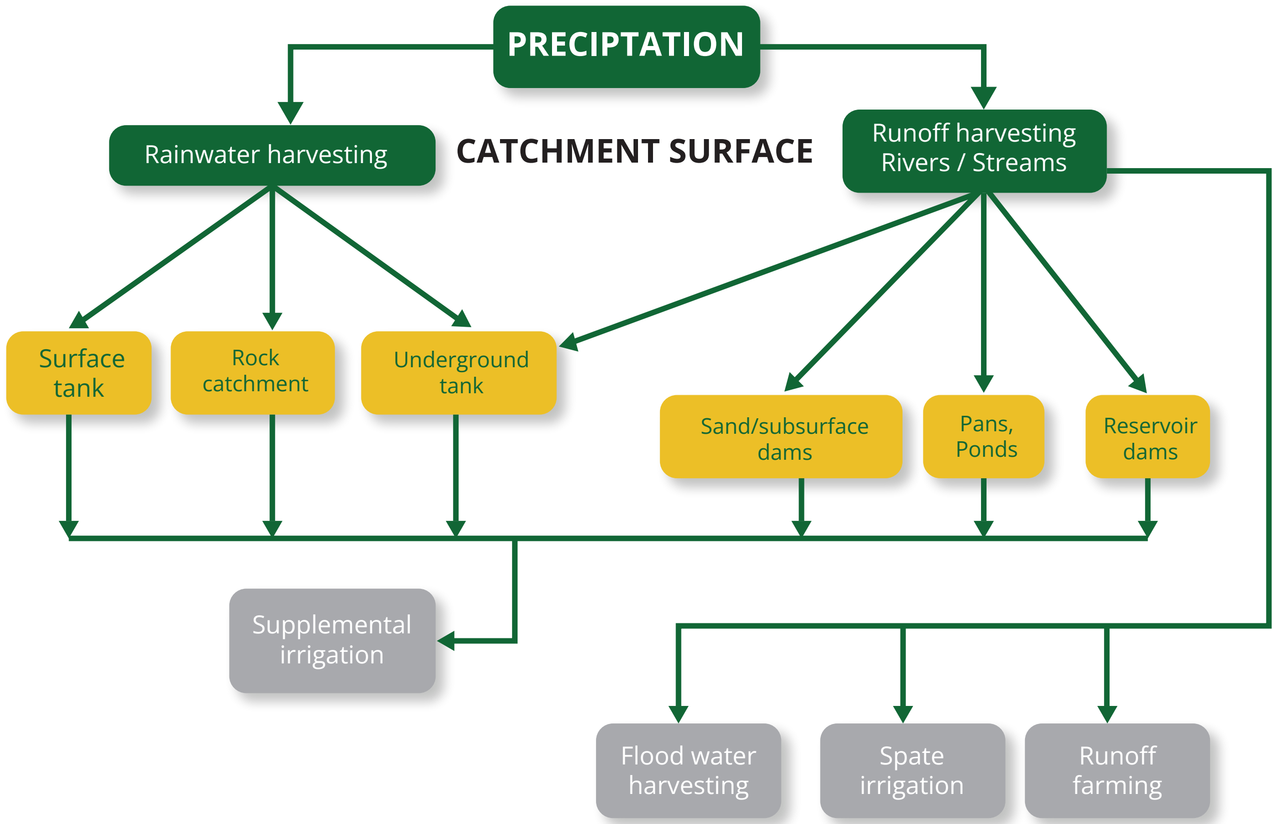


Figure 2: Overview of water harvesting storage systems

Rainwater Harvesting

The first of the above, rainwater harvesting is commonly understood to be collecting water from rooftops and pavements/built-up areas in vessels or tanks, either above or below the ground, to be used for supplying water for domestic purposes including livestock and limited gardening or irrigation uses. These are typical micro-catchment activities, widely applicable in Nepal and around the world.

Runoff water harvesting and/or floodwater harvesting

This type of water harvesting is a group of catchment level activity, both macro and micro, that collects or impounds flood waters or runoff in streams, lakes or rivers, or diverts flood waters with the use of structures in the rivers to farms and required areas. The flow regime is primarily turbulent runoff and channel flow through rivulets, gullies, streams and rivers. Spate irrigation is a form of floodwater harvesting where the flood is diverted and spread over agricultural land. Runoff farming channels water from upland catchments to lower-level agricultural areas, thus concentrating rainfall collected to a smaller area.

In basin or sub-basin scales, rivers and streams or their high flows can be stored behind dams in reservoirs and the water is withdrawn when required. The predominance of turbulent runoff and channel flow of the catchment water is a characteristic of these systems.

Depending upon the volume of the storage it can be tanks, pans, ponds, lakes or reservoirs. The availability of water, location and headwater available can provide opportunities for multipurpose uses including drinking, irrigation, hydropower, recreation, the preservation of the ecosystem and biodiversity. Smaller scale pans and ponds can also be constructed to utilize the local topography to aid in local water supply, irrigation and livestock use.

Subsurface Dams

Subsurface dams are barriers built in sandy rivers/beds to capture subsurface flows and extract them for consumptive uses: for drinking, livestock and irrigation. These are feasible in certain sandy river beds and alluvial fans with high permeability, even though there may not be visible water on the river beds. Arjun Khola in the Dang area of Lumbini Province has such suitable conditions in Nepal and other flashy river beds in the Terai and valleys can be a source for limited water supplies.

Aquifer Recharge, Storage and Recovery

Sub-surface aquifers or groundwaters can also be recharged by delaying runoff, infiltration ponds, spreading runoff over large areas and delaying flood propagation. Injection wells and boreholes can also be constructed to store water during excess flows, store water in underground mounds in suitable aquifers and retrieve them as required using mechanical pump sets. The water thus injected, stored and extracted, generally termed artificial recharge or aquifer storage and recovery (ASR) , is well understood (Sharma and Ray, 2011) and developed in USA, Australia, Europe and other countries around the world to bank water, though there may be some physio-chemical changes to water as surface water mixes with the groundwater in the aquifer.

Recently, in the Indian subcontinent, groundwater infiltration has also been suggested for storing floodwaters and alleviating flood problems downstream (Pavelic, 2015) as well as addressing water scarcity in post-monsoon season (Sundaravadivel, 2001). Pavelic (2015) introduced and demonstrated the concept of 'Underground Taming of Floods for Irrigation' (UTFI) as a possible approach for addressing both floods and droughts at the river basin scale. Flood waters upstream were directed to infiltration ponds and wells and the groundwater was recharged; this could be tapped during the subsequent dry season, proving to be beneficial in disaster reduction as well as in aiding crop production.

In-situ Water Harvesting

In-situ water harvesting is often practiced in arid and semi-arid areas where rainwateris collected at the field itself. Sheet flow or rill flow occurs from the rain-catchent area adjacent to the run-on agricultural areas, and the moisture is stored in the root zone for direct use of the plants (Prinz, 1996; Oweis, 2017). Extensive literature exists (Prinz, 1996; Critchley and Scheierling, 2012; Oweis, 2017; Mekdaschi-Studer, R. and Liniger, 2013; Yu et al., 2021) regarding this type of water harvesting, and it is often coupled with in-the-field soil and water conservation activities. This kind of water harvesting can be beneficial in drier parts of Nepal that have long dry spells and/ or a dry season, such as the phenomena witnessed in the rain shadow areas beyond the Western Himalayas in Mustang, Dolpo and Karnali regions (Gandaki Province and Karnali Province) where the annual precipitation is as low as 200 mm and the eight months precipitation during the dry season is less than 100mm in large areas.

2.3 Advantages and Risks of Water Harvesting

Water harvesting provides water and food security

Water harvesting provides water in areas and times of need if the system is carefully planned and operated. It provides drinking water (after treatment), for livestock and agriculture. The large population and related rise in demand for food means that greater pressures are exerted on arable land and water.

Rain-fed agriculture provides a major role in food production and sustaining livelihoods around the world (Rost et al., 2009; Rockström et al., 2010). It constitutes 80% of the world's cropland and produces more than 60% of the world's cereal grains, generating livelihoods in rural areas while producing food for cities (Molden et al., 2011). Rain-fed areas, in most arid and semi-arid zones, with no access to water for supplementary irrigation, are deficit in terms of overall water required to support the cultivation of crops customary in the region.

The rainfed and upland crops even in humid and sub-humid areas are likely to fail or yield lesser when the rainfall is not adequate to support the optimum plant physiology and crop yield (Critchley and Scheierling, 2012) when the dry seasons are too long or the rain-intervals are longer.

Water harvesting augments groundwater

The basic principle of holding on to rainwater or runoff water provides greater opportunities for water to infiltrate and augment groundwater. This provides additional benefits to the users in the area or further away in restoring depleting groundwater levels, increasing access to, and safety of, water.

Water harvesting aids integrated water resources management

The activities of planning, executing and operating water harvesting require that the community and different sectors – land-use, forest conservation, watershed conservation, utilities, local user groups and rural and municipal governments come together and deal collectively on various issues coming up. These can include the use of upland catchment area resources, reforestation and soil conservation, water quality, waste disposal and management, water scheduling and usages, agriculture practices and production, marketing and distribution of products as well as credits and agriculture inputs, etc.

Water harvesting aids rural economy and jobs

Water harvesting reduces the drudgery in fetching water and improves the economic activities at rural areas that are increasingly left vacant by urbanization and migration. It helps retain labor and youth in rural areas creating jobs in spin-off benefits, such as those used in the processing of agriculture products, and greater opportunities in agro-forestry enterprises, tourism and travel industries, which could be attracted by means of good watershed and water harvesting activities.

Risks and disadvantages of water storage structures

There may be certain risks and disadvantages with water harvesting structures. These include safety and accidents at the water bodies – storages, ponds and reservoirs. There also exist risks of dam failures or flooding downstream or harboring pests and vectors such as mosquitoes for increased incidences of malaria.

The primary disadvantage of water harvesting systems is that it may curtail the traditional uses of unimpeded water along the river bodies or generate conflicts between upstream and downstream users as the water used at one stretch will always undermine availability at the other end. The upland watershed, which may need to be managed to prevent erosion and pollution of water which is being stored, may be controlled or prohibited from carrying out other developments such as urban construction, tillage agriculture, uses of pesticides, herbicides and fertilizers, or other underground storage tanks for chemicals or gasoline products, etc.

Another disadvantage, especially from large storage sites include the inundation of fertile valleys, settlements, displacements and even affecting the riverine ecology as the dam will create a barrier in the watershed preventing fish and aquatic species traveling up and down stream.

2.4 Contextualizing Water Harvesting in Nepal

The average annual precipitation ranges from less than 200 mm to areas with more than 5000 mm. Nepal suffers from "too much and too little water" due to the seasonal variability of rainfall. Nepal's climate is a wet summer monsoon with a dry winter influenced by elevation, orientation and location in a subtropical latitude. There is a strong spatial variability in precipitation even within the basin and sub-basins. The water harvesting approaches of the arid and semi-arid regions may not appear relevant in Nepal, but seasonal droughts make them essential in safeguarding the livelihoods of the rural population. Some river basins/sub basins are drier and water is deficit in winter seasons. Traditional rain-fed agriculture and upland crops are susceptible to droughts and moisture deficits in soils which severely impact crop yields and are increasingly becoming unsustainable. Due to this reason, storage of water and later release for irrigation becomes essential to increase cropping intensity and agricultural yield, or for availability of reliable energy through hydropower generation. Water security becomes an issue during non-monsoon season.

UN-Water (2013) defines water security as follows:

The capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability.

Governments are urged to create a water-secure society as one of the top priorities across the globe (UN-Water, 2013). Water harvesting is expected to provide that security and is recommended in Nepal's policy recommendations, such as those made by ADB and the World Bank such as the National Water Plan 2005 (WECS, 2005), National Adaptation Plan (GoN, 2021)or national planning documents.

A careful analysis of storage options, sizing and location needs to be done to minimize the risks mentioned earlier as often the value of controlled and in-hand water will outweigh the costs and risks incurred with suitable planning and design. Water harvesting and storage are essential for Nepal to address its temporal and seasonal water shortages and economic water scarcity. The next Chapter describes the situation in detail.

3. WATER HARVESTING NEEDS OF NEPAL

3.1 Background Information

The physiographic distribution of Nepal and its ecological zones are shown in Figure 3 with a typical North-South transect with climatic zones. Out of the total area of 147,516 km² almost 86% of the nation is covered by hills and mountains. Forests cover about 43.4% of the area of the country while agricultural land is 24.1%, almost half of the latter is in Terai – southern flat lands. The average annual precipitation ranges from less than 200 mm to more than 5000 mm with the average value estimated to be 1830 mm (MOFE, 2019). The spatial distribution of annual values is shown in Figure 4 from a DHM (2015) report, the primary rainfall is driven by the summer monsoon emanating from the Bay of Bengal.

The middle mountain region (Figure 3), with an elevation from 1,000 to 3,000 masl and a temperate climate, averages 275-2300 mm of rainfall. It is intersected by large rivers flowing north to south. The High Himalaya region includes the Himalayan Range and the areas north of it. The climate here is of the tundra and arctic variety.

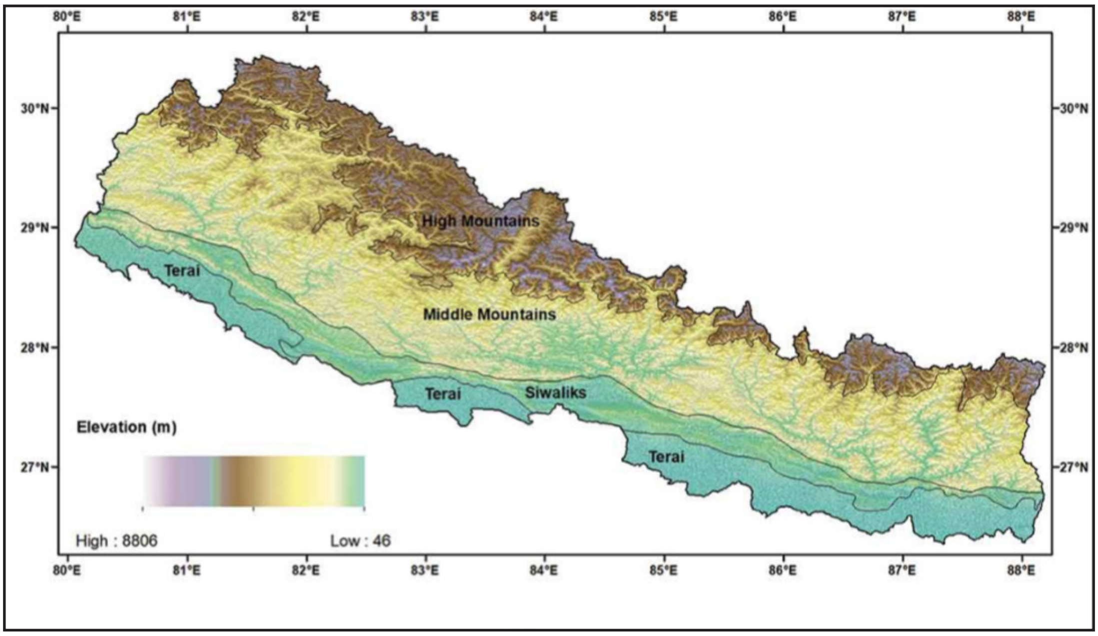
It has an extremely rugged terrain with steep slopes and deep valleys. Precipitation is estimated to be 150-200 mm, though the weather instrumentation is rather scarce, and a major portion of it occurs as snow in higher altitudes. The Terai and the valleys in the middle mountains are prime areas of agriculture and residential areas. The Irrigation Master Plan (IMP, 2019), states that, out of the total net agricultural lands of 35,610 km^2, about 64% of this land or only 22,650 km^2 has the potential for irrigation, while the rest is not economically irrigable.

The present population of Nepal is estimated to be about 29.192 million (Central Bureau of Statistics (CBS), 2021). Agriculture is the mainstay of Nepalese, 60% of the population list agriculture as their prime occupation (CBS, 2012) contributing to a quarter of the gross domestic product (GDP). The GDP per capita is estimated to be USD $1,085 for FY 2019/20 (CBS, 2020).

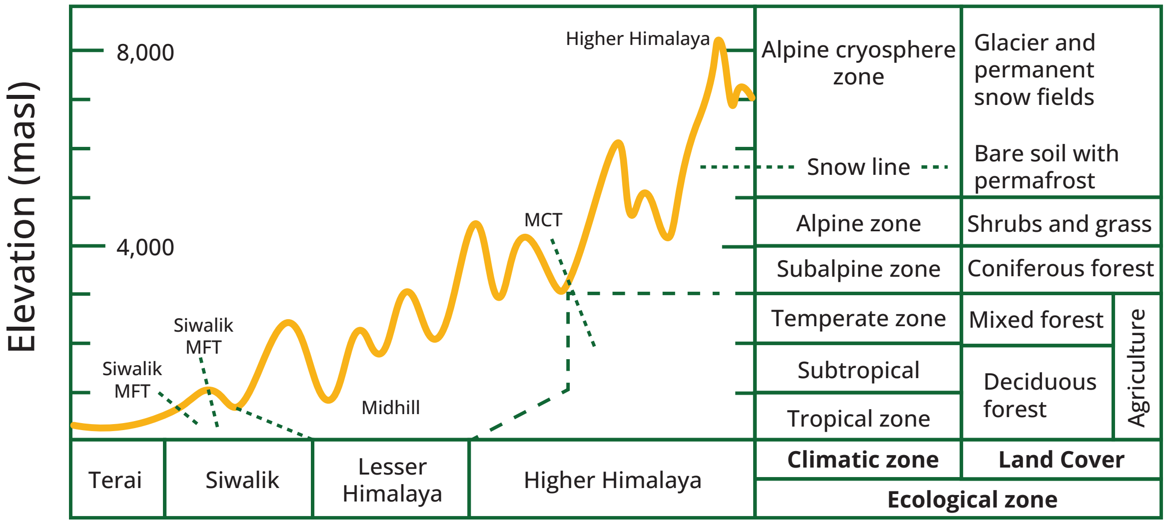
Rapid development of the agriculture sector with good irrigation facilities is essential to absorb and retain labor in agriculture to transform the economy, while the development of renewable energy is essential for import-substitution and meeting nationally determined contributions (NDCs) commitments. Water plays a pivotal role in supplying irrigation to enhance agricultural productivity as well as provide energy through hydropower generation to fuel further economic activities.

3.2 Surface Water

The average annual total surface water available in the country is estimated to be 225 billion m^3 per annum, equivalent to about 7,700 m^3/person/year. Nepal's freshwater accounts for an estimated 2.27% of the total world supply (WB and ADB, 2021). The major river systems of Nepal are Mahakali, Karnali, Narayani (Gandaki) and Koshi. These rivers originate from the Himalayas and beyond, are fed from snow and glaciers and have appreciable dry season flow. These four river systems drain almost 73% of the land mass and account for 78% of the average annual run-off volume. In annual averages, these are water surplus basins, but the seasonal variations are extreme and the rivers flow in deep valleys such that the mountain terraces have no feasible reliable sources of water for irrigation and other usages.



(a)



(b)

Figure 3: Map of (a) Physiographic zones, and (b) Schematic of ecological zones along a typical North-South Transect of Nepal. (Source: Nepal et al., 2021)

The other rivers, Babai, West Rapti, Bagmati and Kankai drain only 8% area of the country, with large flows during rainy seasons but very low to almost no flows in the dry season. These are water deficit basins. The rest of the nation is drained by Mechi, Kamala and other southern rivers in the Terai. These are extremely seasonal flow rivers with high floods in the summer monsoon and almost no flows during the dry season.

The large seasonal variation in rivers suggests that the optimum utilization of the water resources requires water harvesting storage or reservoir projects that store annual floods and provide water round the year to required areas. This can be equally true at the local micro-catchment to basin scales where suitable sites exist. Inter-basin diversions are also a strategy to supply water to deficit areas.

3.3 Groundwater

Nepal has good resources for groundwater in the Terai region, the net total rechargeis estimated to be 13 billion cubic meters per year. Groundwater has been used for drinking water and irrigation development, through the use of shallow tube wells (STW), and deep tube wells (DTW). Inner valleys and hill slopes also provide local groundwater that has been used for drinking water, irrigation and industrial usage at places. The Kathmandu Valley groundwater abstraction has exceeded sustainable yield so that it has drastically lowered, drying up natural springs and ponds.

Similar cases have also been reported to dry up hillside springs and water sources in the hills and mountain areas in the Himalayas, where changes in land use patterns reportedly couple with climate change impacts; reducing flows or even drying up springs in (Adhikari, et al., 2021; Shrestha et al., 2017; Tambe et al., 2012.) It is also understood that the change in consumption patterns may have increased water demands in these hill springs and caused over-exploitation. Climate change-related changes in precipitation causes increased intensity, but the reduced number of events of rainfall would reduce the net infiltration to soil profile and recharge of the groundwater. Reduced but intense rain events accelerate runoff and limit subsurface recharge.

Suitable water resource management activities at the local levels need to be implemented to maintain healthy watersheds to arrest erosion, thereby improving water quality as well as arresting nutrient and soil loss, and retarding overland runoff to augment the recharging of groundwater.

3.4 Rainfall Patterns

Figure 4 shows the distribution of mean annual precipitation in Nepal (DHM, 2015) and Table 1 shows the precipitation for different rain seasons. The precipitation ranges from less than 200 mm to more than 5000 mm, and the majority of this aggregate takes place during the 4 months (June -September) of monsoon.

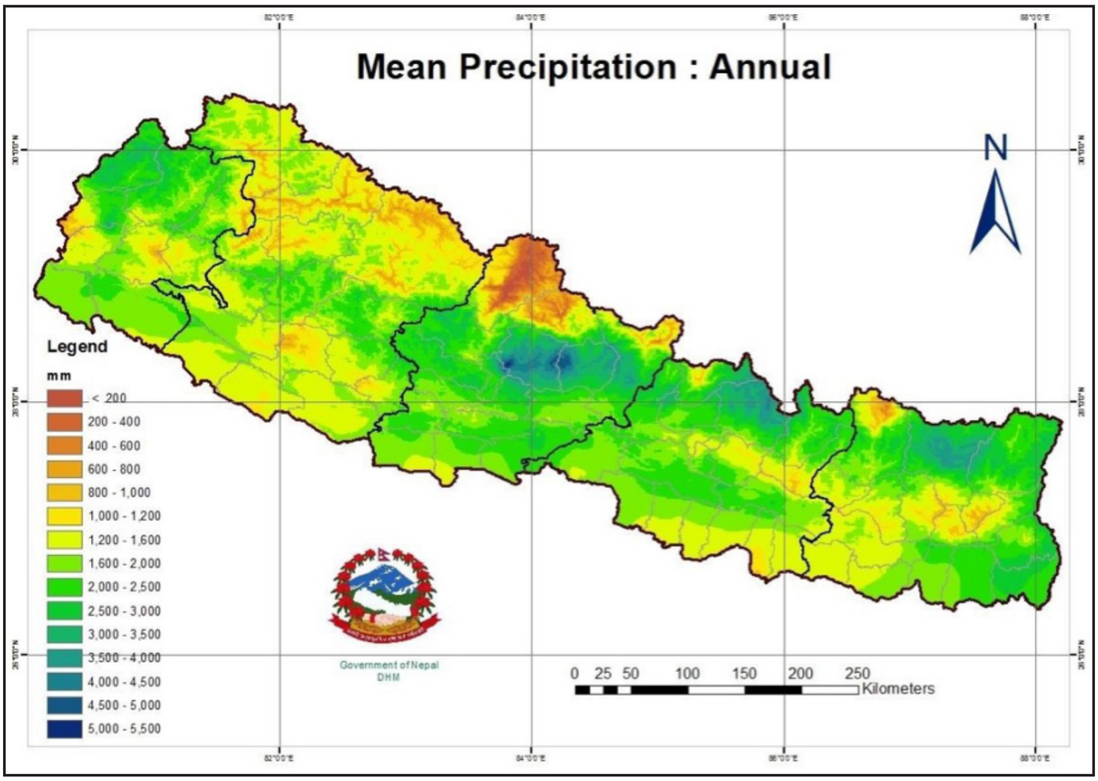


Figure 4: Mean annual precipitation of Nepal (Source: DHM, 2015)V

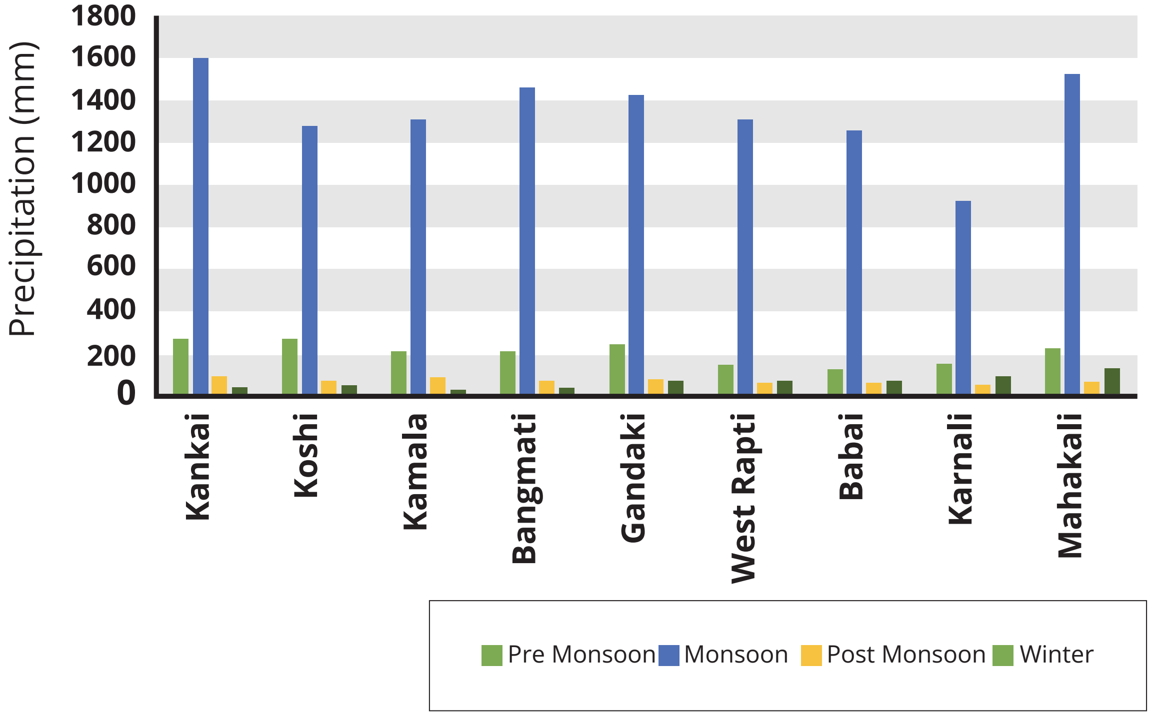


Figure 5: Mean precipitation in different river basins in Nepal for different seasons (Source: WECS, 2019)

Table 1:Mean Annual Precipitation for different River Basins in Nepal for different seasons (adapted from: WECS, 2019)

River Basins	Total Mean Annual Precipitation	Monsoon (June - Sept)	Post-monsoon (Oct- Nov)	Winter (Dec- Feb)	Pre-monsoon (Mar-May)	Non-monsoon (Oct -May)
	(mm)	4 months (%)	2 monthsn (%)	3 months (%)	3 months (%)	8 months (mm)
Kankai	1998.9	79.6	4.9	1.9	13.6	408.2
Koshi	1666.7	76.6	4.6	3.0	15.7	389.3
Kamala	1628.9	80.1	5.0	1.9	13.0	323.8
Bagmati	1794.9	81.6	4.2	2.3	11.8	330.3
Gandaki	1823.0	78.7	3.9	4.1	13.4	388.9
West Rapti	1586.6	82.8	3.9	4.2	9.1	273.6
Babai	1513.6	83.2	4.1	4.6	8.1	254.5
Karnali	1225.1	75.8	4.2	8.0	12.0	297.1
Mahakali	1924.8	79.2	3.0	6.5	11.3	399.9

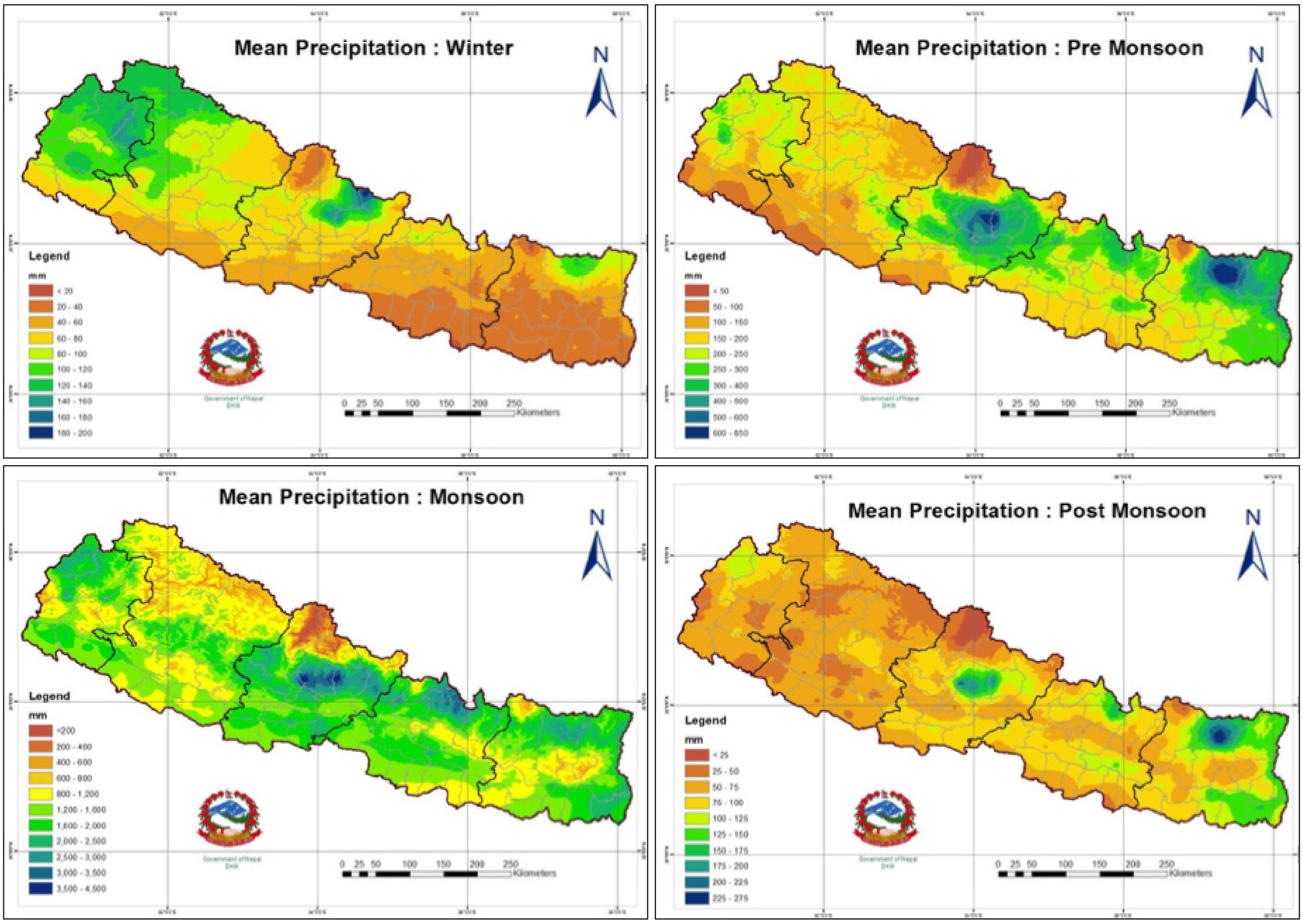


Figure 6: Distribution of mean precipitation for various seasons (Source: DHM, 2015)

It is seen, in Figure 5, that the bulk of the rainfall, about 76-83%, occurs during the summer monsoon period – four months of June-September and the rest of the eight months is quite sparse rainfall. Table 1 shows the annual precipitation amounts in mm for different river basins in Nepal and is shown in percentage for monsoon (June-Sept, 4 months) post-monsoon (Oct-Nov, 2 months), winter (Dec-Feb, 3 months), pre-monsoon (Mar-May, 3 months). The last column shows the rainfall for 8 months (Oct-May) and it is seen that it ranges from about 250 mm to 400 mm; these values approach the annual semi-arid rainfall values (250 -500mm).

3.5 Water needed for irrigation and hydropower

These figures and data suggest that for Nepal to enhance food productivity by growing more crops in a year, it is essential that there exists some storage systems that stores water and provide irrigation water. There are severe shortages in rainfall or stream flows in Nepal for winter or spring crops. The aggregate March river flows in Nepal are adequate to provide irrigation only to an area of 750,000 hectares while the irrigable area is 2.265 million hectares (IMP, 2019).

The nation has primarily run-of-the-river hydropower schemes and only one reservoir (storage) hydropower scheme, the Kulekhani Hydropower Project with an installed capacity of 60 MW. This is a 114 m high rockfill dam with a storage volume of 85.3 million cubic meters. The current hydropower mix is primarily runoff the river schemes, with low production during the low flow season in winter as Nepal is currently net exporting.

The government had also completed the feasibility study of the Budhigandaki Hydropower Project with a gross storage capacity of 4,467 Mm^3, and a surface area of 63 km^2 at full supply level. The scheme is a seasonal storage type, storing monsoon excess flows and releasing stored water during the lean flow season augmenting the normally low flow volumes. The rated discharge is 672 m3/s and the storage scheme is to be operated for peak loads.

Similarly, the Dudhkoshi Storage scheme identified as a national priority project is a storage scheme with a dam height of 220 m and a generating capacity of 635 MW. The storage capacity is estimated to be 1,581 MCM. It's tailrace, through a 13.3 km tunnel, will release water in Sunkoshi river down-stream of the proposed Kamla diversion. This may be in conflict with the Sunkoshi-Kamala diversion as the storage project may render the diversion impossible.

Energy security is a prime objective of Nepal's, and a number of storage and run-of-the-river are in various stages of implementation. The government's approach is stated to be, in principle, the adoption of multipurpose projects that accrue multiple benefits for the nation.

The benefits, at local scale with constructions of ponds and lakes will also be beneficial to a variety of uses such as for livestock, aquaculture, and recreation as well as preservation or restoration of ecosystems.

It must also be recognized that the water harvesting can be useful and needed not only for human-centric developments, but also are equally important in terms of preservation of the ecosystem (Yu et al., 2021), rejuvenation of wetlands and ponds as well as reviving water bodies impacted by human developments and compounded by climate impacts.

4. POLICIES RELATED TO WATER HARVESTING

There are a number of policies promulgated recently that are related to use of water and addressing climate change. The National Adaptation Plan (GoN, 2021) is the latest climate change-related document that lists water stress and lower water availability during the winter season as a major climate risk that needs to be addressed with priority. The Vulnerability and Risk Assessment exercise (MoFE, 2021) done for the water resources sector recommends that climate adversities (high seasonal fluctuation of river flow; risks from climate-induced disasters; spatial and temporal water scarcity) be advertised, and benefits be maximized.

The study also recognizes that seasonal variability will impact hydropower efficiency and production. The hydropower sector, which is the major source of energy generation in Nepal, will suffer more from seasonal water fluctuation and variability and the consequences of climate-induced disasters in the energy infrastructure and services. The National Water Plan 2005 strongly states that due to extreme seasonal variations in water availability in the Nepalese rivers, all future programs will have to focus on the storage of water during the rainy season and its proper utilization during dry periods.

The government of Nepal recently, in December 2020, released the new Water Resources Policy, 2020; which has adopted the principles of IWRM and the river basin organizations to advance the management of water resources. The goal of this new policy is "to sustainably conserve, manage and to carry out multipurpose development of the available water resources contributing to the economic prosperity and social transformation of the country."

National Climate Change Policy 2019

The National Climate Change Policy supersedes the old Climate Change policy of 2011. The policy, in terms of water resources and energy, states that energy security will be ensured by promoting multiple uses of water resources and the production of low carbon energy. The policy says that the following strategies and working policies shall be included:

- Technologies for storage, multiple purpose uses and efficient usage of water will be developed and promoted in risk-prone areas and settlements considering the effects of climate change on the availability of, and access to, water.
- Rainwater harvesting ponds will be constructed for groundwater recharge and their multiple uses.

Besides, the large dam, reservoir, and river diversion plans will be impacted due to the seasonal variability (too much water and too little water). The storage capacity of water resources needs to be increased naturally and artificially to meet the seasonal water scarcity impacted by climate change and to meet the scattered demand of water service areas.

Gaps and Need in the Policies

The existing policies, though proactive in terms of adapting to climate change and setting the context, have still not been able to excite and implement investments in watershed harvesting. The policies at the provincial and local municipalities level are either absent or lack enough prominence to be translated to practice. Watershed harvesting practices transect across different sectoral areas of land use and planning, forest and soil conservation, hydrology and water resources as well as the fields of water supply, agriculture and energy. These policies are in silos, addressing and concerned within their domains. These seldom complement efforts in other sectors which may be impacting their own spheres of influence and jurisdiction.

It is needed that the policies and directives be made more visible and followed with enabling outlays and programs to implement them. The need to recognize cross-sectoral role of watersheds and water harvesting systems need to be recognized and promoted by all sectoral policies. There are also needs to strengthen capacity and develop technical skills to identify suitable locations, implement o direct all levels of governments – federal, provincial, local levels. There must be policies to support these multi-sectoral policies ensure that water security, food security and even energy security aspects are truly addressed and achieved at various scales and landscapes.

5. CONCLUSION

Climate change impacts in Nepal, as well as around the globe, primarily manifest through water; with changes in the precipitation pattern altering the availability of water (Pörtner, et al., 2022). Impacts can be delayed onset of the rainy season or even extended periods of drought or the period between successive rain events that can create water stress and competition between different uses. High seasonal fluctuation of rainfall and river flow; spatial and temporal water scarcity and the increasing incidences of droughts brought about by climate change suggest that water harvesting is a viable strategy to enhance resilience and adaptation to climate change. Simple storage tanks or reservoirs in a suitable location can be formed with dams to capture water and store it for subsequent use.

In Nepal, the wet monsoon season – with four months of heavy rain and eight months of sparse rains - dictates that water be stored in rivers for irrigated agriculture as well as hydropower production. Climatic conditions do not require the storage to be extended beyond the year and thus are relatively smaller in size, in comparison to multi-year storage dams required in other countries around the world.

The government's policies also direct people towards adopting water storage, inter-basin transfers, conservation ponds, water collection ponds, water recharge systems, and water reservoirs to augment water and food and energy securities at multiple scales. These policies need to be made more action oriented backing up by suitable budgetary outlays with programs and projects. Capacity building at all levels, federal, provincial and local governments should be carried out in tandem with professional inputs in identifying locations, designs, specifications and prototype developments.

The following points summarizes the needs , drawing upon the discussions made in the previous chapters, of a water harvesting or storage system.

Water Demand and Aspirations: Demand for water exists in Nepal due to the extended dry season, with low rainfall as well as the need to enhance water, food and energy securities. Communities are rather possessive of water and therefore the aspirations of the society will need to be scrutinized assessing the convictions and safeguarding our own environment and society.

Variability in precipitation: Extreme variability in precipitation creates water stress as well as provides an opportunity to adopt water harvesting so that the water can be stored and used as required.

Natural storage locations: It would be important that the topography and geological analyses yield suitable locations for storage. These include river valleys, pans, existing lakes and reservoirs, etc., which are available in Nepal.

Vulnerability to floods and droughts: The greater the vulnerability and risks of extremes of floods or droughts, the higher is the possibility of agreeing to a water harvesting or storage option. Storage options also retard floods, attenuate peaks and provide some relief to downstream areas exposed to floods. With climate change impacting severity of hydrological phenomena, the question of whether to build or not build storage reservoir may not be pertinent at all, the rhetoric may shift to what size of systems are required.

Capacity building for water harvesting: The capacity at various government levels to recognize, sensitize, plan, design, implement, construct, operate and monitor water harvesting systems at various scales is urgently required.

Nepal suffers from water storage gaps and increasingly variable precipitation, threatening sustainable development. These threats will be further amplified by climate change impacts. Water harvesting is an attractive option for Nepal that increases the amount of water per unit cropping area, reduces drought impact and enables the use of run-off beneficially thereby increasing the adaptive capability and resiliency of the water sector to impacts of climate change.

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