Inventory of Water Resources and Water Bodies in Kandara and Kateni Sub-Watersheds

Report of a Study Commissioned by SAHAMATI under the Project Nature Based Solution (NbS) in Kandara and Kateni Sub-Watersheds Supported by WWF

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Executive Summary

1. Kandara and Kateni sub-watersheds in Kailali District represent a critical ecological interface between the fragile Chure hills and the fertile Terai plains. This landscape is hydrologically dynamic, hosting a complex mosaic of springs, streams, wetlands, and aquifer systems that constitute the water sources on the which biodiversity of the area and the livelihoods of the people living in the area is based. However, recent decades have witnessed growing water insecurity driven by erratic climatic patterns, unmanaged infrastructure expansion, and shifting land-use dynamics. The water sources and systems in the two sub-watersheds have also undergone accelerated changes. This report, based on the study in the area commissioned by SAHAMATI, a national level development organization engaged in the promotion of Nature Based Solutions (NbS) for the conservation of water sources and water bodies in the two sub-watersheds under WWF support, provides a comprehensive inventory and assessment of water sources and systems within the two sub-watersheds. Commissioned to inform evidence-based freshwater interventions involving nature based solutions (NbS), the study aims to: i) produce inventory and map all water sources (springs, streams, ponds, lakes) and systems (canals, tube-wells) in the area; ii) assess the current state of water sources and systems in the area, including seasonal availability, ecological value and stress factors; iii) analyze governance, documenting local knowledge, management practices and institutional mandates with regards to conservation and restoration of water sources and systems; and iv) Recommend Nature-based Solutions (NbS) to enhance water security, resilience, and ecosystem integrity.

2. The study employed a mixed-methods approach combining spatial analysis, hydro-ecological assessment, and participatory inquiry. Spatial mapping involved use of free access and high-resolution satellite imagery and GPS field verification to delineate sub-watershed boundaries and locate and categorize water sources and water bodies. Field assessment involved physical observation of discharge patterns, infrastructure conditions (canals, intakes), and ecological health (riparian status, siltation). Extensive engagement with local communities through Focused Group Discussions (FGDs) and Key Informant Interviews (KIIs) was used to capture traditional knowledge, historical trends, and livelihood dependencies. Alongside evaluation of the regulatory environment and the functionality of user committees and local government units with regards to their readiness to promote NbS for water conservation and restoration.

3. Springs originating from the Chure foothills are the primary contributors to dry-season flows in local streams and wetlands in the area. The inventory reveals a distinct north-south distribution, with contact and fracture springs common in the foothills and depression springs in the lower plains. A significant number of springs are drying or becoming seasonal due to climate-induced rainfall variability and physical disturbances from rural road construction that disrupt sub-surface flow paths.

4. The sub-watersheds are drained by the Kateni (formed by Baluwa khola and Seti rivers) and Kandara (fed by Guwase, Doda and Chorpani rivulets in the upstream) systems. These streams are "flashy," characterized by violent monsoon torrents and meager dry-season flows. High sediment loads from the Chure hills have raised riverbeds, leading to frequent bank breaches, course shifting, and inundation of agricultural land. Infrastructure bottlenecks (bridges, culverts) constraining the flow path further exacerbate flood risks.

5. The study inventoried 55 natural ponds/lakes (44 in Kandara, 11 in Kateni). These water bodies are vital for groundwater recharge, biodiversity, and traditional irrigation. Many natural wetlands are degrading due to encroachment and "commercialization." Municipal contracting for fish farming has led to mechanical excavation and the construction of embankments. While economically profitable, these interventions block natural runoff and seepage flow in the water bodies undermining their ecological functions and sustainability.

6. Agriculture is the dominant livelihood, historically supported by *Tharu* tradition of community-managed irrigation systems (FMIS), such as Tedi and Gurgi canals and numerous other stream and pond/lake fed canal systems for irrigation. There is a marked transition from collective surface-water management to private groundwater extraction. The proliferation of shallow tube-wells (STWs) and deep tube-wells (DTWs) has boosted cropping intensity but weakened traditional water governance institutions. While groundwater reserves are currently productive, the combined pressure of reduced recharge (due to land-use change) and unregulated extraction poses a long-term depletion risk.

7. Water governance in the area is characterized by fragmentation. Contestation continues to prevail between the Forest Division Office claiming jurisdiction over water bodies in forest areas and Local Governments (Municipalities and Rural Municipalities) claiming constitutional authority over local water resources and water bodies. This contestation is produced from existing ambiguity in regulatory instrument which hinders coordinated conservation efforts. Municipal engagement is largely limited to infrastructure construction and revenue collection (gravel mining, fishery contracts), with minimal focus on ecological conservation. The transition to private ownership and use of shallow tube-wells and pumps to access water for irrigation and domestic uses have eroded the social capital that existed earlier for the maintenance of communal canals and ponds.

8. The study advocates for shifting from purely gray infrastructure interventions to ecosystem-based approaches for the conservation and restoration of water sources and systems in the area, involving: i) Source Protection: Protecting spring-sheds and recharge zones in the Chure hills through reforestation and bioengineering; ii) Wetland Revitalization: Restoring natural inflow/outflow regimes in ponds and prohibiting mechanical alterations that seal aquifer connectivity; iii) River Corridor Management: Implementing riparian buffers and bio-engineered embankments (e.g. through bamboo, vetiver and kans combined with flexible infrastructures) rather than concrete walls to manage floods and sediment, and iv) Groundwater Management: Promoting Managed Aquifer Recharge (MAR) through recharge pits and conservation ponds to counterbalance extraction.

7. Using the evidences from the study the study a number of NbS options for spring source protection and restoration, conservation of ponds and lakes, improvements in hydrology and ecology of streams, groundwater recharge and management of groundwater of the study area have been recommended.

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1. Introduction

1.1 Background

Chure (Siwalik)-Terai landscape is one of the most ecologically dynamic, hydrologically connected and socio-economically interdependent regions of the country. Situated at the interface of the fragile Chure hills and the Terai plain, this landscape hosts a mosaic of water sources and water bodies--springs, streams, rivulets, wetlands, lakes and ponds, marshes, alluvial aquifers and gravity- and groundwater-fed water systems for irrigation and domestic/municipal water supply, each offering critical ecological functions and supporting diverse livelihood needs. These water sources also underpin the hydrologic connectivity between the hills and plains, regulate seasonal water availability, recharge groundwater, sustain wetlands and river ecosystems and serve as essential buffer against climatic and hydrological variability.

Within this landscape, Kandara and Kateni sub-watersheds, located in Kailali District, hold particular ecological and socio-economic significance for number of reasons: i) these drain the sensitive Chure terrain which is characterized by unstable geology, high erosion potential and rapidly changing surface and sub-surface flow dynamics; ii) seasonal streams flowing through the two sub-watersheds contribute to groundwater recharge for use in the southern plain while numerous natural ponds, wetlands, and community-built water systems also recharge groundwater and enhance local water retention and ecological diversity. The area supports a dense population whose livelihoods depend heavily on rain-fed and irrigated agriculture, livestock rearing and forest based products (fuelwood, fodder, thatching material and edible plants). In recent decades, this area has been facing drying and depletion of springs, shrinking wetlands, declining surface and groundwater reliability, siltation of ponds, and growing competition between domestic, agricultural and ecosystem water needs. Developing deeper understanding of the area and its water sources has become critically important to address water-related vulnerabilities intensifying in the area.

Ecologically, Kandara and Kateni sub-watersheds are located in Basanta Corridor, which links Suklaphanta National Park and Bardia National Park in Nepal with Dudhwa National Park in India and provide important natural habitat and movement passage for wildlife across the three contiguous conservation areas. The wetlands, rivulets and forested recharge zones in the area provide interconnected microhabitat and ecological niches to sustain natural vegetation and wildlife. Socio-economically, the water bodies in the two sub-watersheds meet household water needs, support climate-sensitive agriculture based livelihoods and maintain social institutions for water use and governance. *Tharu* community, the indigenous habitants and largest social group, of the area have rich tradition of community-led natural resources management and self-governing institutions for the management of water and other natural resources. The observed pressures arising from climatic variability, land-use change, unmanaged extraction and infrastructure expansion heighten the urgency to systematically assess and respond to the current state of water sources and water bodies in the area.

Comprehensive inventory of water sources, water bodies, and water-use systems in Kandara and Kateni sub-watersheds, contained in this report, is therefore strategically important to inform the options of water and natural resources management in the area. For WWF Nepal, inventory of water sources and systems lays the scientific foundation to advance evidence-based freshwater interventions to promote conservation, restoration, and sustainable utilization. By documenting the spatial distribution, seasonal dynamics, ecological values, local knowledge and practices and institutional arrangements for governance of water sources and systems, the inventory helps identify and prioritise nature based solutions (NbS) for water source protection, watershed restoration, wetland rehabilitation, and improved local water management, worth promoting in the area. It also provides critical insights into the drivers of change and the stresses undermining water security and to guide the intervention designs that are ecologically sound, community-supported, and adaptable to climate uncertainties. For development organizations like SAHAMATI, which works directly with the people in organizing and implementing NbS at the local level, inventory of water sources at the sub-watershed levels provide the entry point to prioritize the work and roll them on the ground involving the people and agencies of local, provincial and federal governments.

1.2 Objective of the Study

The overall objective of the study is to produce comprehensive inventory of water sources and systems in Kandra and Kateni sub-watersheds in Kailali District, assess their existing state (seasonal availability, usages and change dynamics), local knowledge and practices around their use and institutions relating to their management to inform ecosystem based approaches and NbS that would contribute to their sustainable utilization, at present and in the future. This overall objective is targeted by accomplishing following specific objectives:

i. to identify, map and categorize water sources (springs- seasonal and perennial, streams and rivulets; natural and manmade water bodies- ponds, lakes, tanks, swamps/ marshes and water systems (dug-wells, stone spouts, shallow and deep tube-wells and community and public built canals and water supply systems) in the study area;

ii. to assess the existing state, involving seasonal availability and changes, usage and ecological and livelihood importance of the water sources and systems;

iii. to identify and assess the factors and processes accumulating stresses on the water sources and systems and the threats (existing and potential) building on them and undermining their sustainable utilization;

iv. to document local knowledge and practices and the institutions involved in the governance and management of water sources and systems;

v. to recommend actionable agenda on ecosystem management and integration of NbS targeting conservation/protection, restoration and sustained utilization of water sources and systems in the area.

1.3 Intended Use of the Inventory

The study targeting preparation of inventory of water sources and water bodies in Kandara and Kateni sub-watersheds is expected to provide knowledge base to guide informed, integrated and forward-looking decisions in watershed and freshwater management. By systematically documenting the distribution, condition, seasonal dynamics, use patterns and management arrangements of water sources and systems, the inventory will enable stakeholders, from local governments to community water-user groups and conservation organizations, to design interventions that are ecologically grounded, socially acceptable and resilient to changing hydro-climatic conditions.

At the heart of its purpose, the inventory provides the empirical foundation for ecosystem-based watershed management. The spatial mapping and assessment of conditions of springs, streams, wetlands, and manmade water systems help identify ecologically sensitive zones, groundwater recharge areas, degraded riparian stretches, and threatened wetlands where targeted restoration and source-revival measures are most needed. This enables the prioritization of conservation actions such as springshed management, wetland rehabilitation, riparian stabilization, and catchment protection, ensuring that interventions enhance overall ecosystem function and water security.

For municipal and local government planning, the inventory offers a comprehensive and up-to-date evidence base to incorporate freshwater resources into planning processes, those relating to land use zoning, investment strategies in small water systems for productive uses and protection of the water sources. Mapping of water sources and systems and analytical findings relating to them can inform decisions related to drinking water expansion, irrigation development, road alignment, settlement growth, disaster risk reduction and groundwater utilization. By grounding local planning in hydro-ecological realities, the inventory would inform more sustainable allocation of local resources, including water, which would enable the municipalities to avoid actions that would inadvertently exacerbate water stress, degrade wetlands or disrupt recharge processes.

1.4 Nature Based Solutions (NbS) for Protection of Water Sources

Nature-based Solutions (NbS) are interventions targeted to protect, sustainably manage and restore natural (or modified) ecosystems to address societal challenges, such as water scarcity, watershed degradation, pollution, and climate-induced hydrological extremes while also provide human well-being and biodiversity co-benefits (IUCN, 2016; Cohen-Shacham et al., 2016). In the context of conservation of water sources and systems, NbS comprise a suite of ecosystem centred interventions, such as watershed and spring-shed management, reforestation and assisted natural regeneration, wetland rehabilitation, river corridor greening, promotion of soil and water conservation structures and practices, rangeland management, and agroforestry, all of which enhance ecosystem functions critical to hydrological regulation. These solutions improve groundwater recharge, stabilize slopes, reduce runoff and erosion, maintain base flows, purify water through natural filtration and strengthen socio-ecological resilience against climate variability and escalating anthropogenic pressures (WWF, 2020; ICIMOD, 2021). By leveraging ecological processes to conservation and restoration of water sources and systems, rather than relying solely on engineered infrastructure, NbS help restore the integrity of water systems at landscape scale while offering cost-effective, adaptive, and locally appropriate pathways for long-term water security and climate resilience building.

NbS align closely with Nepal's ecological realities, steep slopes of hills and mountains, monsoon-dominated climate and hydrology, increasing climatic variability and expanding anthropogenic pressures on land and water. Empirical evidences from diverse regions of Nepal shows that watershed restoration, community forestry, wetland protection, bioengineering and rehabilitation of riparian vegetation can significantly enhance the reliability, quality, and resilience of water sources while assuring benefits for biodiversity and livelihoods.

Climatic variability across the country, also in the study area, manifests through erratic rainfall, incidences of prolonged dry periods, occurrence of high intensity rain events and shifting monsoon patterns. This variability in climate combines with the land-use changes, infrastructure development, agricultural expansion, riverbed mining and forest fragmentation to accelerate the drying of springs, erosion, sedimentation, and water insecurity. Studies in the middle and lower mountains show that more than 70% of rural households depend on springs for domestic and agricultural uses, yet many springs are declining due to a combination of climate-driven recharge reduction and landscape disturbances (ICIMOD, 2019). NbS offer a pathway to regenerate natural recharge processes, stabilize slopes, and restore hydrological functions that conventional engineering often does not address sustainably.

Spring and groundwater source revival through NbS is among the strongest areas of available evidences in Nepal. In Kavre, Dhulikhel, Sindhupalchowk, and Bhojpur, integrated recharge interventions, such as forest restoration in recharge zones, development of infiltration ponds, vegetative trenches and protection of upper-catchment forests have led to measurable increase in spring discharge (ICIMOD, 2019; Paudel et al., 2020). In Dhankuta and Tehrathum, LI-BIRD supported watershed management showed improvements in spring flow reliability and reduced seasonal drying after community-led reforestation and bioengineering measures were implemented to restore the degraded slopes. These interventions worked by enhancing infiltration, reducing surface runoff, and rebuilding soil organic matter, thereby increasing the resilience of water sources to climate-induced rainfall variability.

Community forestry, one of Nepal's most successful environmental governance innovations, has demonstrated substantial hydrological and ecological benefits. Long-term assessments in community forest areas, undertaken in Kaski, Dolakha, and Lamjung, have shown that community-managed forests exhibit improved vegetation cover, higher soil moisture retention, reduced surface erosion, and lower sediment yields compared to degraded open-access forests (Sharma et al., 2017). These improvements translate into more stable base flows and reduced flashiness of water channels in the catchments, offering downstream benefits for irrigation systems, rural water supplies and small hydropower operations. Forest restoration also strengthens resilience to climatic extremes, as healthy forests buffer high-intensity rainfall and support groundwater recharge even under variable precipitation patterns.

Wetland conservation and river-floodplain restoration is another area of application of NbS. The Terai's wetlands (such as Ghodaghodi Lake complex in Kailali, Beeshazari Tal in Chitwan, Jagadishpur Reservoir in Kapilvastu and Koshi Tappu) provide essential hydrological functions, including water storage, flood attenuation, groundwater replenishment and water purification. Studies around Beeshazari Tal in Chitwan has shown that wetland conservation combined with catchment management reduces sediment inflow and improved water quality, benefiting both biodiversity and local agriculture (Ramsar/IUCN Nepal reports). Similarly, floodplain restoration and riparian vegetation rehabilitation along Koshi and Narayani rivers have been found to contribute to stabilize the river banks, reduce erosion, and buffer communities from monsoon floods.

In the middle and lower hills, bioengineering measures for slope stabilization using native grasses, shrubs, and trees, are proven effective in restoring degraded slopes, controlling gullies and reducing sediment loads in water systems. Case studies from Baglung, Syangja and Gorkha demonstrate that bioengineered slopes maintain structural stability better under intense monsoon rainfall than hard engineering alone, while simultaneously improving infiltration and water flow in nearby springs (DoSCWM, 2018). These measures help reduce watershed sensitivity to both extreme rainfall and land-use disturbances.

More importantly, NbS assures social and livelihood gains. By improving water availability, reducing hazard exposure and increasing ecosystem productivity, NbS measures reduce vulnerability and support diversified livelihood options, such as increased availability of fuelwood, fodder, non-timber forest products, fisheries, and tourism. Participatory watershed governance, a hallmark of NbS in Nepal, is known to strengthen local institutions, promote community stewardship to water and other natural resources and facilitate adaptive responses to climatic and anthropogenic stressors. Empirical evidences in Nepal establish that NbS deliver long-term, adaptive and low-regret solutions that complement engineered infrastructure. Scaling them would require cross-sectoral planning, sustainable financing, robust monitoring, and integration into local governments' water resource management frameworks.

2. Description of the Study Area

2.1 Physical and Environmental Settings

The Kandara and Kateni sub-watersheds located in the central part of Kailali District drain into Mohana River flowing along the western and southern boundary of the district. Geographically, the two sub-watersheds occupy the southern slope of Churia hills, the transition zone at the foot hills, called the Bhabhar zone, and the southern (Gangetic) Terai plains. As such the area lies in Mohana sub-basin in larger Karnali River basin (see Figure 1). The location of the two sub-watersheds in Siwalik-Terai interface makes them hydrologically significant and environmentally sensitive for strong ecological interdependence between upstream hill slopes and downstream fertile plains of Terai. Geographical area of Kandara and Kateni sub-watersheds is 50474.82 and 24189.86 ha respectively, which if put together is 23.08% of the area of Kailali District (3235 km^2).

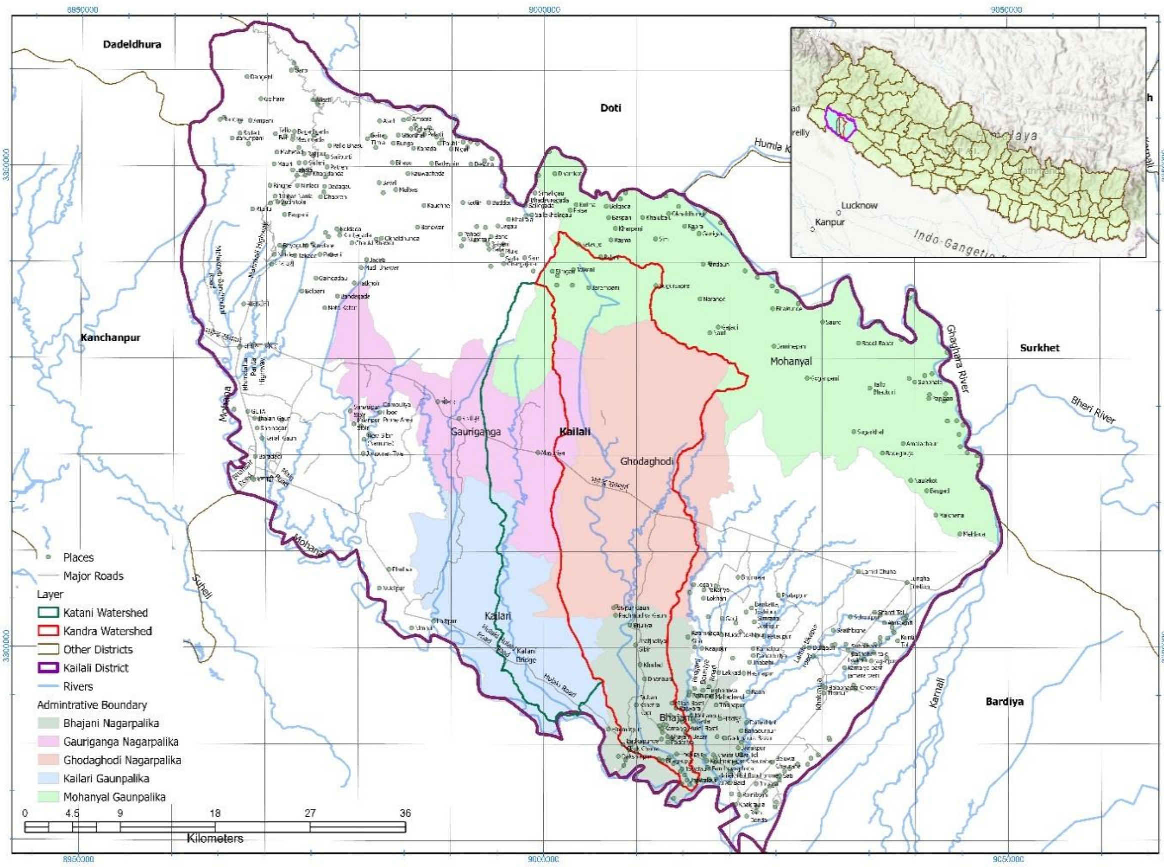

Figure 1: Location map of the Study Area

Physiographically, the Chure is characterized by narrow ridges, steep escarpments, deeply incised gullies, and fragile sandstone-dominated hill formations. Elevation typically ranges between 200–900 m, with micro-watersheds fed by short but dynamic first- and second-order streams. The lower Terai plain is comparatively flat, consisting of alluvial formation. Coarse sediments and gravelly terraces in the foot hills and Bhabhar zone form important groundwater recharge zones. This physiographic transition from north to south is a defining feature of western Nepal's Chure-Terai freshwater landscape, including that of the study area, influencing water retention, drainage patterns, erosion processes and spatial configuration of wetlands and human settlements.

The climate of the area is tropical to sub-tropical monsoon type with a pronounced wet season from July to September that contributes roughly 75–85% of annual rainfall (DHM, 2021). Annual precipitation in the Kailali Siwalik–Terai belt typically ranges from 1,500–2,200 mm, though high inter-annual and spatial variability is common due to monsoon dynamics and increasing climate variability. Summer is hot and humid, while winter is mild and dry, creating a strong seasonal contrast in water availability. These climatic conditions strongly influence streamflow regimes, seasonal pond dynamics, groundwater levels, and the reliability of springs. The observed climatic trend of the study area synthesized from DHM's assessment (DHM, 2017) is provided in Box-1.

Box 1: Climatic Trend of the Study Area

Climatic conditions in the study area reveal notable shifts over the last four decades The period since 1990 reveal clear patterns of increasing variability in rainfall, rising temperatures and heightened hydrological extremes. While total monsoon rainfall has fluctuated around the long-term normal, the nature of rainfall has changed significantly. DHM monsoon summaries indicate a marked rise in short-duration, high-intensity rainfall events, particularly after 2010, contributing to flash floods, sediment surges, and rapid river swelling in the Kandara–Kateni–Mohana River Systems. At the same time, monsoon onset and withdrawal have become increasingly irregular, with more intra-seasonal breaks affecting soil moisture, agricultural operations and flows in the local streams.

Temperature trends show an even clearer signal. DHM’s national climate trend analysis documents a statistically significant rise in both maximum and minimum temperatures in the western Tarai, with minimum temperatures increasing most rapidly. These warming trends have been particularly pronounced since 2010, resulting in hotter pre-monsoon months, higher evapotranspiration rates, and more frequent warm nights. Such shifts further exacerbate dry-season water stress by increasing evaporative losses from stored soil moisture, wetlands and shallow aquifers.

Dry-season precipitation (winter and pre-monsoon) has also weakened over past four decades. DHM’s seasonal reports consistently show below-normal winter rainfall in several recent years, including 2020, 2021, and 2023. Reduced winter and pre-monsoon recharge windows directly affect springs in the Siwalik foothills, contribute to early drying of ponds, and lead to measurable declines in shallow groundwater levels in Bhajani and Kailari. This has heightened dependence on groundwater pumping while simultaneously shrinking natural recharge opportunities.

Hydrologically, the cumulative effect of these climatic shifts has made the sub-watersheds more “flashy” and flood prone. Since 2010, multiple flood events, driven by extreme rainfall bursts, have been recorded in the Mohana basin, with downstream impacts in Bhajani and Kailari becoming severer. Increased sediment loads from intense rainfall on fragile Chure slopes have further aggravated the siltation of streams, ponds and canals. (source: DHM, 2017)

Land use in the two sub-watersheds comprise mosaic of public and community forests, agricultural terraces in upland areas, mixed cropping patches in middle slopes and rain-fed and irrigated croplands in the downstream areas of Terai. Forests, mostly comprising Sal *(Shorea robusta)* and mixed hardwood species (Saj, Karma, Sisoo, Bijay Sal, Harro, Khair and others) and undergrowth play a critical role in regulating infiltration, reducing surface runoff and maintaining micro-climatic conditions. Settlement expansion, road construction and agricultural intensification have modified land cover patterns in recent decades, influencing both surface hydrology and groundwater recharge processes. This land use of the study area has also important biodiversity linkages.

The Chure forests in upper catchments connected to the forests in Terai plain form the part of the north–south ecological corridors that connect the Churia hills with the Terai forests, supporting wildlife movement and genetic exchange. Wetlands, ponds, and small rivers provide habitats for fish, amphibians, aquatic plants, and migratory birds, while riparian vegetation acts as a buffer stabilizing streambanks and maintaining ecological integrity. These linkages are central to the freshwater and landscape conservation priorities of WWF Nepal, particularly in maintaining ecosystem services that benefit both people and biodiversity of the area.

2.2 Socio-Economic and Institutional Context

The socio-economic landscape of the Kandara and Kateni sub-watersheds reflects a long history of human settlement shaped by ecological conditions, livelihood needs and evolving development trajectories. Prior to 1960, the Siwalik foothills and the adjoining Terai plains were sparsely populated due to malaria epidemic, dense forest cover and limited accessibility of the area. There were only scattered settlements of indigenous *Tharu* communities until 1960s. With the eradication of malaria in the late 1960s and subsequent national resettlement initiatives, population gradually expanded in the Terai plains and the lower slopes of the Siwaliks. The settlement pattern at present involve migrants from adjoining hills and mountain Districts (Doti, Bajhang, Dadeldhura, Baitadi) settled in the northern part, near the foot hills and along the East-West Highway, mixed hills migrants and Tharu in the middle and mixed Tharu, Madhesi and Muslims in the southern part. This settlement pattern in the area reflects the layered history, combining traditional Tharu villages in the south, linear roadside settlements of hills migrants along the highways and district roads in the middle and scattered hill-slope hamlets inhabited by migrants seeking cultivable land and livelihood opportunities in the recent past.

Infrastructure growth in Kandara and Kateni sub-watersheds, like in other part of Kailali District, has accelerated in recent decades. Road networks now penetrate further deep into the scattered settlements of Chure hills, improving mobility but also contributing to slope destabilization and altered surface runoff patterns. Expansion of rural roads, market centres, electricity distribution and cellular mobile connectivity, small-town growth in lower reaches has improved living conditions but also increased demand for water for domestic and agricultural uses. The spread of groundwater-based irrigation systems, expansion of piped drinking water schemes and construction of small canals have transformed local hydrology. However, unplanned infrastructure development, particularly road construction without adequate drainage and slope protection works, has contributed to accelerated erosion, flooding and inundation, sedimentation of streams and water bodies and drying and depletion of springs at several locations.

Administratively, the geographical boundary of the two sub-watersheds extend into five local governments- Kailari Rural Municipality, Bhajani Municipality, Ghodaghodi Municipality, Gauriganga Municipality and Mohanyal Rural Municipality. These local government bodies hold primary responsibility in organizing, managing and regulating the management and use of water and other natural resources within their administrative jurisdiction. The presence of community forest user groups, drinking water user committees, farmer-managed irrigation systems and local conservation groups forms a critical institutional layer for natural resources governance. These community institutions play central roles in mobilizing labour, devising resource allocation rules, maintaining local infrastructure and enforcing norms of use. Their effectiveness however varies depending on leadership, resource availability and connectedness technical and financial support.

3. Methodology

The methodology used in the study combined spatial analysis, participatory inquiry and systematic field observation (see Figure 2). A mixed-methods design was used to capture the physical, ecological, socio-institutional, and functional characteristics of water sources and systems across Kandara and Kateni sub-watersheds. This methodology ensured triangulation of data to develop contextual understanding of the condition, use, pressures and management water resource and systems in the area.

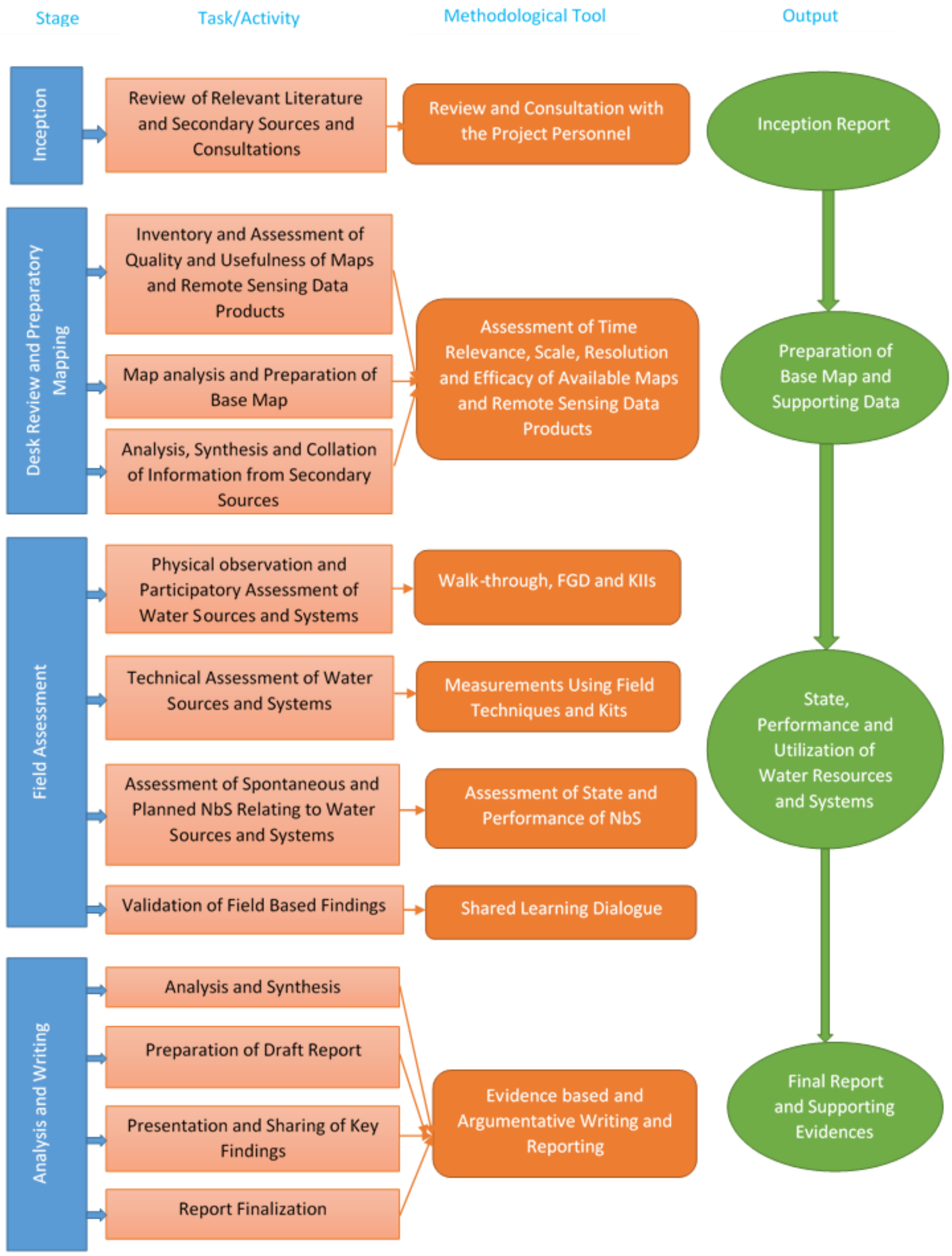

Figure 3.1: Methodological Framework

3.1 Spatial Mapping- Locating and Categorizing Water Sources and Systems

Spatial mapping was utilized as the key to the inventory process. High-resolution satellite imagery (USGS and ESA), google image and digital elevation model of the areas (ASTER and PULSAR DEM from Earthexplorer) were used to delineate the boundary of the two sub-watersheds- Kandra and Kateni. A preliminary mapping of the water sources and water bodies (stream, lakes, ponds and canal systems) which could be identified on the google image, was accomplished from the interpretation of base map before proceeding to the field work.

In the field work these water sources and water bodies were visited and their physical, institutional and ecological characteristics and change dynamics were recorded. Transect walk in the area and the discussions/interactions with the people allowed identifying and mapping water sources, such as springs, marshes and tube-wells (shallow and deep) located in the area that could not be distinguished on the google image. These water sources were geo-referenced using SW Map, a GPS enabled cellular mobile based App developed for natural resources mapping. This allowed to capture precise location, elevation, catchment position, land-use context and ecological and hydrological changes and stresses emerging from them.

Using the mapping process, stated above, spatial layers were developed to categorize water sources based on type, hydrological function, protection status, seasonality and current use. The mapping process also identified areas sensitive to erosion, recharge zones, degraded riparian belts, and critical linkages among land use and surface water systems. The resulting spatial database provided a visual and analytical platform for municipalities and WWF Nepal to guide planning, prioritize conservation investments, and monitor changes over time.

3.2 Physical Observation

Transect walks/surveys across representative sections of the sub-watersheds were conducted to assess the ecological and hydrological settings influencing water availability and use. These observations allowed the team to examine terrain gradients, vegetative cover, recharge potential, erosion hotspots, and land-use transitions from upper slopes to lower plains while also validate the mapped water sources and water bodies.

In the course of the physical observation, manmade infrastructures developed on the water sources and water bodies, such as intake and canal alignment of agency and farmer managed irrigation system, tube-wells, locations of community water supply systems, spring source protection and restoration of lakes and ponds were also identified to assess their functionality and integrity. In physically observing these human built systems, attention was paid to note the signs of erosion and land degradation, leakage, sediment accumulation, structural damage, and unsustainable extraction practices.

3.3 Field Measurements/Assessment

Field based measurement involved assessment of water flow of spring and stream sources using such field techniques as float and flood/flow marks and depth of water to estimate storage volume of ponds and lakes. Assessment of water quality of springs, streams and pond/lakes at selected locations was carried out using test kit made available by Environment and Public Health Organization (ENPHO). This involved assessment of selected water quality parameters- pH, nitrate, phosphate, ammonia and chloride. Although this kit based assessment is not a substitute for laboratory test, this did provide indicative values of these parameters to relate to existing ecology and change processes as revealed by the people using them.

3.3 Participatory Assessment

A range of participatory tools were employed to capture local knowledge, use patterns and governance practices around the water resources and water bodies, as detailed below-

i. Focused Group Discussion

A number of focused group discussions (FGDs), involving at least one in each water source/body/system, were conducted involving different groups of users-- famers, women groups, forest user groups and water user groups, to gather insights on water storage/flow trends, seasonal reliability, traditional water management norms, livelihood dependencies, and community-led conservation efforts. These discussions helped contextualize and also collate quantitative data with lived experiences. Engagement with user committees offered practical insights into understanding the value of the past and ongoing interventions, adequacy of maintenance and upkeep, water-allocation rules, conflict resolution practices and challenges in source protection.

ii. Key Informants' Interviews

KIIs with senior citizens, social/thought leaders, school teachers and officials of the federal and provincial government agencies, those relating to Water Resources Development and Irrigation (Irrigation Division Office), Forestry (Forest Division Office), Soil Conservation and Watershed Management, Agricultural Development (Agricultural Knowledge Centre and Primer Minister Agricultural Modernization Program) allowed to understand historical perspectives on water source shifts, changing rainfall patterns, forest cover dynamics, and institutional challenges. This was also used as means to validate the information obtained from secondary sources.

iii. Interaction with the Institutional Stakeholders

Consultations were held with municipal officials involved in the technical units, elected representatives and representatives of forest and water user groups and personnel associated to provincial and federal government agencies. These interactions provided valuable insights on existing plans, regulatory frameworks, infrastructure investments and perceived gaps in water governance.

3.4 Analysis and Synthesis

Analysis and synthesis involved: i) Spatial analysis in GIS environment, ii) Synthesis of qualitative evidences, iii) Assessment of seasonal variability, stresses and threats, iv) Assessment of ecological and livelihood importance, and v) Institutional assessment.

i. Spatial Analysis

GIS-based spatial analysis was used to interpret the physical distribution, clustering, and landscape context of water sources. This involved: a) mapping all inventoried water sources and systems using GPS-coordinates, ii) overlaying geological, land-use/land-cover (LULC), slope, and drainage layers, iii) identifying spring belts, recharge zones, and hydrologically sensitive areas, iv) assessing proximity to settlements, agricultural zones and forest areas, and v) detecting spatial patterns of stress, such as sources located near eroding slopes, agricultural expansion fronts or unregulated extraction zones.

Spatial clustering analysis helped reveal areas of high water source density, potential ecological corridors, and zones where cumulative pressures may be undermining water security. The spatial layers were also used to identify opportunities for NbS integration, such as riparian buffer restoration, slope stabilization, wetland rehabilitation, and recharge enhancement.

ii. Synthesis of Qualitative Evidences

Qualitative information from FGDs, KIIs, community interactions, and institutional consultations were systematically synthesized across following themes: a) seasonal reliability and perceived changes in water availability, ii) local knowledge on recharge, discharge, and watershed processes, iii) livelihood uses (drinking, irrigation, livestock, domestic, environmental and cultural), iv) community management practices and norms, v) perceived threats (drying, extraction, pollution, infrastructure failure), vi) narratives on land-use change, forest cover dynamics and rainfall variability.

Narratives of different stakeholders and groups of users were compared to identify convergence, divergence, and gaps in understanding. This provided a deeper and more reliable picture of hydrological changes, pressures on water sources, and institutional functionality.

iii. Assessment of Seasonal Variability and Threats

Assessment of seasonal variability and associated risks/threats were assessed through a combination of qualitative accounts, transect observations, and hydrological context analysis. The assessment of seasonal variability was accomplished through: a) perceived changes in flow and storage of water between monsoon, post-monsoon, winter, and pre-monsoon periods; b) perceived changes in the shallow groundwater levels and stream flow patterns, and c) perceived drying and depletion of spring and stream sources, including weakening of previously perennial sources.

Synthesis of outstanding and emerging stresses on water sources and their usage involved assessments of one or more of following dimensions: a) over-extraction for irrigation and domestic uses, ii) forest degradation and declining recharge zones, iii) siltation and sedimentation in ponds and canals, iv) pollution from domestic wastewater, solid waste, and agrochemicals, v) encroachment into wetlands and riparian corridors, vi) structural damage or poor maintenance of water infrastructure, and vii) climate-induced changes such as erratic rainfall or prolonged dry spells.

iv. Assessment of Ecological and Livelihood Importance

Ecological importance of the water sources and systems was assessed using following assessment criteria: a) contribution to local hydrology and recharge, b) role in supporting aquatic/terrestrial biodiversity, c) connectivity to riparian corridors and forest ecosystems, d) sensitivity to land-use change or anthropogenic disturbances, and e) presence of endemic, threatened, or keystone species (in wetlands or forest-linked sources).

Livelihood importance of the water sources and systems was assessed using following criteria: a) number and type of households served by the source/system, b) use diversity (drinking, irrigation, livestock, environmental, cultural), c) importance for food security and agricultural productivity, d) dependence during dry-season stress periods, d) social equity implications, e.g. use by marginalized or water-insecure groups.

Each source was given a qualitative importance rating (high, moderate, low), enabling prioritization for conservation, restoration, or protection measures.

v. Institutional Analysis

Institutional analysis examined the governance arrangements, management effectiveness and regulatory environment shaping water use and conservation. This involved: a) assessment of functionality of water user committees and community-based management groups, b) rules and norms governing water distribution, maintenance responsibilities and resource mobilization for management and upkeep, c) coordination between communities, municipalities and sectoral agencies (of provincial and federal governments), d) policy adherence and gaps in municipal planning and watershed conservation efforts, e) conflict-resolution mechanisms and community capacity to manage risks, f) external support for water management initiatives.

Institutional insights were cross-linked with physical data to identify cases where governance quality significantly influenced water security outcomes. This analysis also informed the formulation of actionable recommendations for strengthening community-based management, improving municipal oversight, and integrating ecosystem and NbS principles into water governance.

4. Inventory of Water Sources and System: Availability, Reliability and Use

This section provides the inventory of water sources and systems identified and mapped in the study area, including assessment of their spatial distribution, flow pattern and the stresses emerging on them produced from climatic and hydrologic variability and extractive uses prevailing in the area. The analysis provided is based on the spatial analysis and the interactions with different groups of users and key informants. The inventoried water sources and systems Kateni and Kandara sub-watersheds disaggregated by municipalities is provided in Annex I and Annex II. Their spatial distribution in the study area is presented in Figure 4-3. A more detailed pattern of distribution of the water sources in each sub-watershed is provided in Annex-III (A-Kateni Sub-Watershed and B-Kandara Sub-Watershed).

4.1 Types of Water Sources and Systems

4.1.1 Spring Sources

A number of springs originate from the Chure foothills in the two sub-watersheds. These springs typically emerge at hillslope breaks and feed into rivulets and streams in the headwater. Mapping of the spring sources in the study involved locating the discharging point (mouth) of the springs sources and assessing their flow pattern, changes in the flow and exiting usage, provided in Table 4.1.

Existence of spring sources, discharging to the surface, were more prominent to the north of East-West Highway in Ghodaghodi and Gaurignga Municipality though these were also in existence in the south of the East-West Highway in other municipalities. Large concentration of the discharging springs was noted within 2 km of north and south of the highway. Dry season flow in the streams and the water stored in the lakes and ponds in the headwater is in fact contribution of the springs. Attempt to mapping the spring sources was limited to those which could be identified by the people and which were located close the settlement and those which could be accessed in the course of the study. It was however not possible to locate and map them all, given their inaccessibility and location deep into the forest. Nonetheless, the spring sources mapped and their characteristics assessed in the study represented the entire area of the two sub-watersheds.

Depression springs were most common type, found south of the East-West Highway, occurring where the land surface was depressed and intersected with the water table. These spring sources, not discharging to the surface, were found associated to the wetlands, marshy patches and seepage-fed ponds though their flow was found susceptible to seasonal fluctuation in rainfall and changes in the land use in the upstream areas. At the foot hills of the Chure, majority of the discharging springs were Contact Springs and Fracture/Fault Springs. Contact springs form where contrasting geological layers meet-- typically permeable sandstone beds overlying impermeable mudstone or shale layers, which are abundant in the lower and Upper Chure formations. Water percolates through the permeable layer until it is forced to flow laterally along the impervious boundary, emerging downslope. Chure region is tectonically active, with numerous fractures, minor faults, and joint sets associated with the Main Frontal Thrust and subsidiary structures. These discontinuities act as conduits that concentrate groundwater flow and create discrete spring outlets. These two types of springs are more localized flow points but have perennial flows which are comparatively less subjected to seasonality. Free flowing spring sources in the study area were identified in mainly Gairiganga and Ghodaghodi Municipality. In Kailari and Bhajani Municipalities, which are located to the south of East-West Highway, the spring source were essentially depression springs feeding the streams and lakes/ponds, which do not appear at the surface.

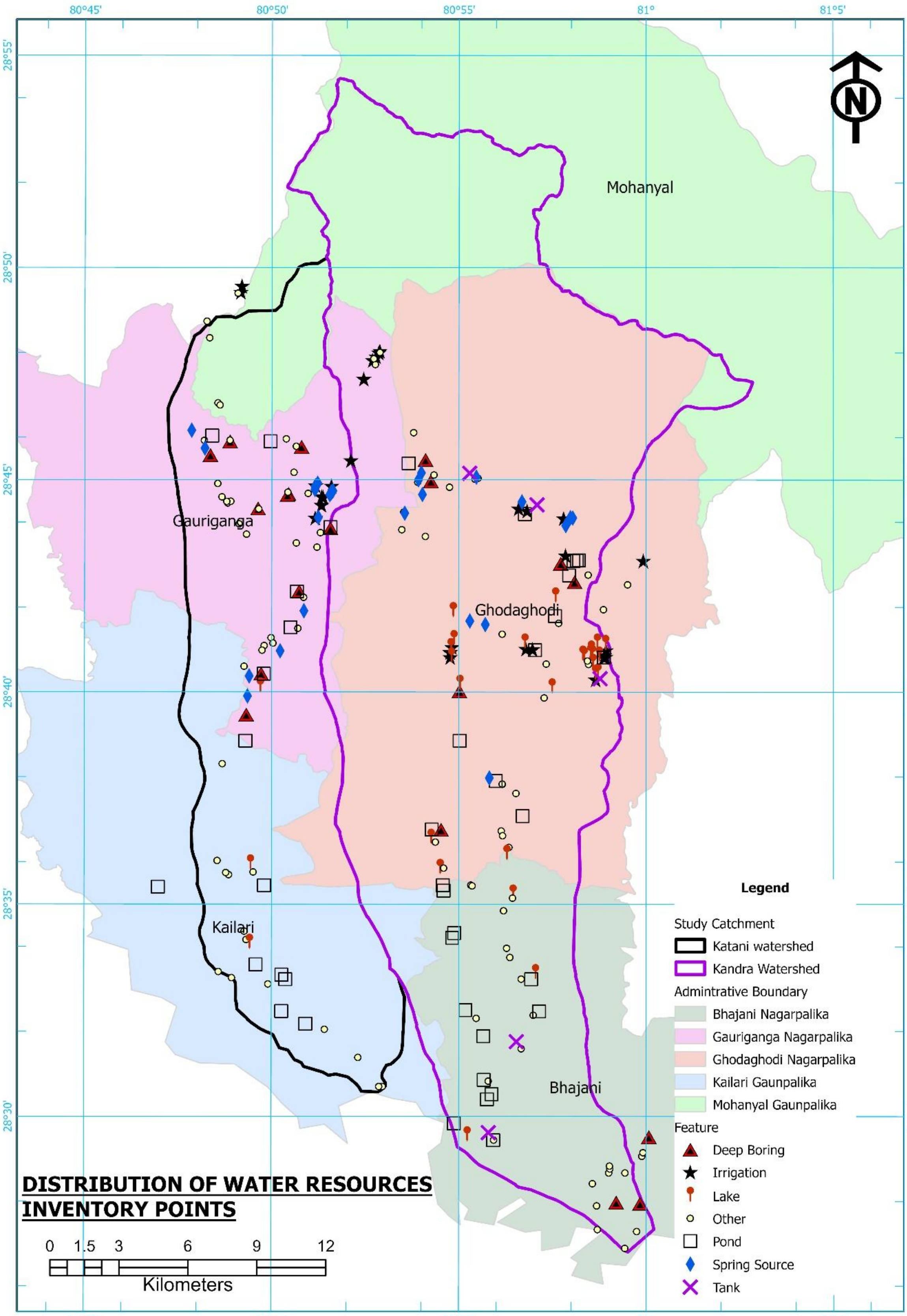

Figure 4.3: Inventory of Water Sources and Systems

Majority of springs in Kandara and Kateni sub-watershed exhibited strong seasonality, with discharge peaks during monsoon and rapid decline in the flow in the dry season. Local communities consistently reported that several springs that once functioned as perennial domestic water sources have increasingly weakened, now showing intermittent flows or drying entirely between March and May. They identified that with the growth in the human settlements expanding in the north, near the Siwalik foot hills and hill slopes and construction of roads, drying and depletion of spring sources in the area was intensified in the recent years.

Table 4.1: Spring Sources by Sub-Watershed and Municipality

Spring Sources	Location	Lat	Long	Elevation (m)
Spring Sources of Kateni Sub-Watershed				
Kailari Municipality				
Spring_Source / Jungle Drain on the way to Lathuwa	Badka Majra Village Kailari 1	28.5961	80.8252	101
Gauriganga Municipality				
Spring_Source at the old course of Baluwa Khola		28.7625	80.8035	131.685
Spring Source/Channel		28.7695	80.7976	137.872
Spring_Source/Channel	Rajiya, Gauriganga 9	28.7353	80.8540	130.864
Spring_Source/Channel		28.7443	80.8591	135.363
Spring_Source/Channel		28.7452	80.8597	134.902
Spring_Source (Bankhet ko muhan)	Bankhet, Gauriganga 9	28.7458	80.8605	145.496
Spring_Source/Channel		28.7451	80.8598	147.672
Spring_Source/Channel	Gauriganga 9	28.7487	80.8538	143.293
Spring_Source/Channel	Shivpur, Gauriganga 9	28.6987	80.8477	122.3
Spring_Source/Channel	Shivpur, Gauriganga 11	28.6829	80.8371	105.6
Spring Source/Channel	Shivpur, Gauriganga 11	28.6730	80.8233	107.9
Spring Source/Channel	Shivpur, Gauriganga 11	28.6652	80.8226	101.7
Spring_Source/Channel		28.7463	80.8525	132.8
Spring_Source/Channel	Ojhuapur, Gauriganga 11	28.7475	80.8526	129
Spring_Source/Dundre Khola, Spring Channel	Baluwatar, Gauriganga 11	28.7415	80.8132	129.182
Spring_Source/Channel	Bauwtar, Gauriganga 11	28.7530	80.8432	137.557
Kandra Sub-Watershed				
Ghodagodhi Municipality				
Bhagatpur Spring Source	Bhgatpur, Ghodagodhi 9	28.752	80.906	126.7
Spring_source feeding Simali Khola	Tikapur, Ghodagodhi 9	28.747	80.912	122.3
Spring_source feeding Gaildub Khola	Aamfata, Ghodagodhi 9	28.751	80.925	117.5
Spring_source feeding Boura Khola natural drain	Godaghodi 8	28.699	80.981	123.546

Some of the spring sources of the area have also undergone intervention in the recent years. People have constructed concrete ring (kuwa) around the discharging point of the spring with the aim to acquire spring water for drinking water use. However, their intervention in making such structures at the discharging point may obstruct the flow path of the springs. People in the area have noted that with the construction of the concrete ring the flow in the kuwa has depleted and also the flowing pint has shifted.

4.1.2 Rivulets and Streams

Mapping and transect assessment revealed that the streams in both sub-watersheds are small, shallow and strongly influenced by monsoon runoff. The stream sources identified in the study area are provided in Table 4.2. Baluwa Khola and Seti Nadi are two major tributaries which meet and form Kateni Khola, which is named Likma Khola near the East-West Highway, Surma Nadi midway and Kateni khola in the southern reaches before confluence with Mohana River. Guwase Khola, Chorpani Khola, Tengara Khola and Doda Khola are tributaries of Kandara River. These streams are perennial flashy with significant monsoon flow but dry season flow diminishes and the flow channel get narrowed.

These streams are shallow to the north of the East-West highway and become deeper after crossing East-West Highway in the south. Several other seasonal streams and channel draining the lakes and ponds and the forest area also join after these streams cross East-West Highway. The flow in the streams increases progressively north to south, which is indicative of contributions of groundwater, springs and return flow from the upstream irrigated areas. The tributaries joining these streams in the north are seasonal rivulets which carry overland flow after heavy rains but the water flow diminishes quickly after the rainfall event. These streams carry huge amount of coarse and fine sediments, including boulders and cobbles in the monsoon causing progressive rise in the streambed. Riparian vegetation on the banks is patchy caused by stream bank erosion and conversion of the stream bank area to agricultural uses.

Table 4.2: Stream Sources by Municipalities and Sub-Watershed

Name	Location	Lat	Long	Elevation (m)	Remarks
Stream Sources of Kateni Sub-Watershed					
Kailari Rural Municipality					
Kateni River Bridge	Kailari 5	28.5521	80.8318	104.4	Bridge at Kateni at ward office
Kateni Mohana Confluence	Bipatpur, Kailari 7	28.5119	80.8811	102.4	
Kateni River	Majhara, Kailari 1	28.5950	80.8143	102.9	Stream bank erosion and river shifting
Jungle Drain on the way to Lathauwa	Badka Majra, Kailari 1	28.5961	80.8252	101	Discharging into Kateni Khola
Gauriganga Rural Municiaplity					
bridge					
Confluence point of Likma (Seti Nadi) and Baluwa Khola	Baluwataar, Gauriganga 8	28.7409	80.8137	135.7	Baluwa Khola joins Seti Nadi and then flows as Likma Khola
Kholsi (near Janjagriti School)	Andaya, Gauriganga 5	28.7416	80.8151	124.5	Discharges into Seti Nadi near confluence point
Dundre Khola	Baluwataar, Gauriganga 8	28.7486	80.8092	132.1	Discharges to Baluwa Khola

Baluwakhola		28.7415	80.8132	129.2	
Seasonal Tributary of Baluwa Khola		28.8123	80.8043	223.7	Located at the Stone Quarry Site
Baluwa Khola Tributary	Sisaure Tole, Gauriganga 5	28.7803	80.8092	157.2	
Shankarpur Culvert Point	Gauriganga 9	28.7795	80.8102	136.6	
Culvert point	Mahadeva, Gauriganga 9	28.7236	80.8535	126.3	
Culvert point		28.7294	80.8550	130.5	
Kholsi Bridge	Gauriganga, 7	28.7463	80.8526	131.1	Drains into Kateni
Natural drain		28.7452	80.8404	137.0	Drains into Kateni
Culvert on Natural Drain	Indrapur, Gauriganga 7	28.7633	80.8442	142.9	Drains into Kateni
Likma Nadi	Aaitha, Gauriganga Ward 11	28.7976	80.8787	213.1	
Likma Nadi	Aitha, Gauriganga 11	28.6850	80.8300	130.4	Vegetated revetment (Jaibik Tatbandha) developed
Katani Nadi	Aitha, Gauriganga 11	28.6832	80.8291	123.5	Ward budget (NRs. 8 lakh) utilized for the development of 28 m long gabion embankment for bank erosion control
Shivpur Khola Bridge Site	Shivpur, Gauriganga 11	28.6881	80.8330	124.1	Fowing from east of Masuriya Bazar
Confluence Point of Shivpur Khola	Lausa, Gauriganga 11	28.6860	80.8339	104.9	Shivpur Khola Confluences Likma Nadi
Kateni Nadi	Masuriya Bazar, Gauriganga 9	28.6769	80.8210	102.2	Confluence of likma Nadi and Katani Nadi, named Kateni this point downstream
Likma Nadi Bridge	Badaiku, Gauriganga 8	28.7253	80.8442	115.4	
Stream Sources of Kandara Sub-Watershed					
Bhajani Rural Municipality					
Kandra Mohana Confluence	Kauwakheda, Bhajani 5	28.4482	80.99047	84	Prone to recurrent flooding and inundation in monsoon
Mohana Old Course	Duduwa Phata, Bhajani 5	28.4556	80.97831	92	Mohana used to flow through this course some two decades back
Kandra Mohana Confluence	Kusum Ghat, Bhajani 3	28.4549	80.99577	88	Dolphin Protection Zone, use of large fishing net restricted from this point to confluence of Mohana in Karnali River

Rapti Khola (Drain)	Theki, Bhajani 3	28.4779	80.98339	86.1	Drains upstream irrigated area; Water is utilized for irrigation at several locations in the downstream areas; Flows to Kandara Khola
Bridge Site of Kandra River	Bhajani	28.6057	80.93897	103.5	
Natural Drain	Ghodagodhi ward no 1 Sundarpur	28.66445	80.95459	117.4	Discharges into Kandra
Ghodaghodi Rural Municipality					
Suspension Bridge at Kandra	Ghodagodhi ward no 10 Pahalmanpur	28.7279	80.9017	115.614	
Kandra Khola	Ranijharokha, Ghodagodhi 10	28.7374	80.89206	123	Kandra Khola Debouches Chure and enters to Terai plain
Flood stream	Kulibhan, Ghodagodhi 9	28.7686	80.89648	148.7	Drains into Kandara Khola
Simali Khola	Tikapur, Ghodagodhi 9	28.7472	80.91242	122.3	Drains into Kandara Khola
Gaildub Khola	Aamfata, Ghodagodhi 9	28.7507	80.92515	117.5	Drains into Kandara Khola
Gaildub Spring Drain	Aamfata, Ghodagodhi 9	28.7503	80.92382	126.5	Drains into Kandara Khola
Doda Khola	Ghodaghodi 7	28.6122	80.93551	102.085	Doda-Kandara confluence; Overflows and inundates Kirtipur village in the monsoon
Doda Khola Bridge	Harinagar, Ghodaghodi 7	28.6306	80.93599	99.581	Doda river bridge site
Sitakunda Spring Drain	Ghodaghodi, 1	28.6895	80.93589	107.263	Drains into Doda Khola
Doda Khola Bridge	Ghodaghodi 1	28.6778	80.95554	111.4	Bridge at East-West Highway
Boura Khola (Drain)	Ghodaghodi 8	28.6991	80.98098	123.546	Drains Chure spring and upstream areas, utilized for irrigation at Sandepani

In the course of this study attempt was made to measure/estimate water flow of the rivers/streams at different locations. The water flow of Kateni river at the bridge section at East-West Highway and at the confluence with Mohana River was estimated at 4.6 and 8.9 m^3/s. Similarly, the water flow of Kandara River at upstream of bridge section at East-West Highway and at the confluence with Mohana River was estimated at 7.6 and 16.5 m^3/s. These flow estimates are based on crude measurement of flow using float and approximate assessment of cross-section of flow channel. Monsoon flow in Kateni and Kandara River may exceed 120 m^3/s and 250 m^3/s near the highway, which may exceed further in downstream as several other rivulets and streams also contribute to the flow.

Kandra, Kateni and Mohana Rivers are known for flood havoc and bank cutting, channel shifting and inundation caused in the adjoining areas in the monsoon. People in Bhajani Municipality suffer from flooding of Kandara and Mohana Rivers in the monsoon very year. An account of flood incidence of this municipality based on the information provided by Mr. Bikram Chaudhary, who is Ward Chairperson of Ward No. 2 and also spokesperson of Bajani Municipality is provided in Box 2 below.

Box 2: Flood Damages in Bhajani Municipality

Bhajani and neighbouring Kailari Rural Municipality have a long history of monsoon flooding and river course change. Monsoon floods driven by Kateni, Kandra and Mohana are known to cause repeated inundation in the area in the monsoon. Frequency of damaging flood events have intensified in the recent years. There have been incidences of serious stream bank erosion, shift in the river course and inundation, causing displacement of hundreds of households living along Kateni and Kandara Rivers in 2018, 2020, 2021, 2022 and 2024.

Mr. Bikram Chaudhary, spokesperson of Bhajani Municipality recalled that streambank cutting and inundation caused by swelling of Mohana and Kandara Rivers has been regular phenomenon in the monsoon over past decade. He attributed the rise in the river bed, Changes in in the rainfall pattern and backwater effect of Karnali River primary cause of flooding and inundation in the area. He shared that there has been significant shift in the pattern of rainfall- incidences of short duration intense rainfall events have increased and whenever such rainfall events continue longer, it results the rivers to swell. Recollecting the incidence of flooding in July-August, 2024 he added "intense and prolonged monsoon rains in early July and again in August 2024 caused Mohana and Kandra to swell and over-flank and breach the banks". Bhajani Municipality was among the worst-hit areas in Kailali in this flood event. Bank cutting and sand cast caused by recurrent flooding has rendered more than 1000 ha of land going out of intensive crop cultivation. Municipality has taken initiative to contract out public land along the river course to landless peasants and contract farmers to cultivate sugarcane, which is tolerant to monsoon flooding and also offers protection from river bank and sand casting in the area. Bhajani municipality has also supported some households in the flood and inundation prone areas to construct houses with raised plinth level to protect the householders from prolonged flooding and inundation in the area. The municipality with the support of development organizations has also established early warning system in the flood prone areas.

People in the area recalled that bed level of Kateni, Kandara and Mohana Rivers have raised in significant ways due to massive amount of sediments brought these streams in the downstream areas in the monsoon. Annual sedimentation of the riverbed has narrowed down the channel waterway, causing the monsoon flow to overtop the bank and inundate and case sand casting in the surrounding agricultural lands. Bank erosion and sand casting on the agricultural lands in the monsoon has led many of the settlements to relocate from the area. They also attributed increased congestion in the north-south flow of the rivers and streams, yet another cause of increased flooding and flood damages in the area. They revealed that parallel East-West road alignments of East-West Highway, Postal Highway and District Roads and narrowing of their waterways at the bridge and road crossing points black the flow of water in the monsoon, which has been responsible for flooding and inundation the recent years.

4.1.3 Ponds and Lakes

The inventory identified as many as 55 natural ponds/lakes in the two sub-watersheds- 11 ponds/lakes in Kateni and 44 ponds and lakes in Kandara sub-watersheds, provided in table 4.3 below. These are essentially naturally formed water bodies, arising from a combination of geomorphic, hydrogeological and tectonic processes (see Box 3). These ponds are located on the public and forest lands. Besides these natural ponds, there are also large number of farm ponds and fish ponds located on the private lands.

Box 3: Formation of Water Bodies in the Study Area

Kandara and Kateni sub-watersheds lie on the geologically active foreland of the Siwalik Range, where tectonic uplift and faulting continually deform the terrain. As the Siwalik foothills rise, they shed large volumes of coarse sediments into the flat Terai, creating aggrading alluvial fans. This geomorphic process produces uneven micro-topography with depressions that easily retain water. At the same time, the area's high groundwater table, fed by Siwalik recharge zones, promotes the formation of perennial ponds and marshes. Seasonal river channel migration, overbank deposition and abandoned channels-- palaeo stream channels and oxbows also create natural basins. Together, these processes generate the dense network of naturally occurring lakes, ponds and wetlands typical of the Kandara and Kateni sub-watersheds.

Table 4.3: Ponds and Lakes by Municipalities and Sub-Watersheds

Name	Location	Lat	Long	Elevation m
Ponds and Lakes of Kateni Sub-Watershed				
Kailari Municipality				
Chhotki Basanta Taal	Basanta, Kailari 7	28.5365	80.8485	98.24
Madgaura Pokhari	Badka Basanta, Kailari 7	28.5414	80.8378	100.10
Rakhauni Taal	Kailari 5, Pawera	28.5558	80.8378	100.70
Rakhauna Taal	Pawera, Kailari 7	28.5540	80.8395	98.20
Kamal Pokhari	Bhaderi, Kailari 3	28.5902	80.7828	104.64
Jamathiya Taal	Badka Majhara, Kailari 1	28.5908	80.8301	104.90
Batkhauwa Taal	Manikapur, Kailari 5	28.5598	80.8264	100.70
Lakthahawa Taal	Badka Majhara, Kailari 1	28.5969	80.8240	108.31
Bhuskhauwa Taal	Damara Harinagar, Kailari 1	28.5657	80.8236	100.80
Pond in Making in Forest Area	Manau, Kailari 1	28.5728	80.8212	109.20
Pond in Making in Forest Area	Manau, Kailari 1	28.5695	80.8220	103.00
Thulo Boksinia Taal	Rampur, Kailari Ward 7	28.5233	80.8718	98.10
Rakhauna Rakhauni Pond Channel to Kateni		28.5343	80.8570	96.70
Gauriganga Municipality				

Private Fish Pond	Gauriganga 5	28.7674	80.8067	142.032
Jodi Pokhari		28.7315	80.8595	133.556
Private Fish Pond		28.7652	80.8327	140.061
Private Fish Pond	Shivpur, Gauriganga 9	28.7062	80.8446	124.4
Private Fish Pond	Shivpur, Gauriganga 9	28.6922	80.8417	121.7
Private Fish Pond	Chamariya, Gaurignga 11	28.6739	80.8298	119.2
Private Fish Pond	Damaripur, Gauriganga 11	28.6476	80.8217	103.7
Chamraiya Taal	Chamraiya, Gauriganga 11	28.6664	80.8284	103.7
Ponds and Lakes in Kandara Sub-Watershed				
Bhajani Municipality				
Changaan Pahalaa Taal	Himmatpur, Bhajani 7	28.4974	80.9145	89.8
Laalkaapariya Taal	Dhanaura, Bhajani 4	28.5414	80.9525	99.8
Khailad Chootki Taal	Khailaad, Bhajani 4	28.5540	80.9489	112.3
Dhunrauwa Taal	Pachmuriya, Bhajani 9	28.5909	80.9096	99.8
Ghor Taal	Pachmuriya, Bhajani 9	28.5888	80.9099	99.6
Soniya Taal	Dongpur, Bhajani 9	28.5721	80.9146	93.4
Rupiya Taal	Dongpur, Bhajani 9	28.5703	80.9138	99.0
Nukli Taal	Ganjahawa, Bhajani 9	28.5419	80.9196	93.2
Bakhari Taal	Pahalmanpur, Bhajani 9	28.5316	80.9276	86.1
Mahuwa Fatuwa Taal	Pahalmanpur, Bhajani 9	28.5145	80.9278	90.2
Chhotki Swasuwa Taal	Bhuruwa, Bhajani 9	28.5088	80.9313	85.4
Badki Swasuwa Taal	Bhuruwa, Bhajani 9	28.5069	80.9293	85.6
Didi Bahini Taal	Bhuruwa, Bhajani 9	28.4908	80.9320	87.8
Korkatla Taal	Khailad, Bhajani 4	28.5539	80.9508	107.5
Laukahawa Bhaukahawa Taal	Bijulia, Bhajani 4	28.5852	80.9409	104.4
Puraina Taal	Charra, Bhajani 7	28.4902	80.9205	86.3
Ghodaghodi Municipality				
Nakrodi Taal	Nakrod, Ghodagodhi 1	28.7019	80.9598	122.0
Ghodagodhi Taal	Ghodagodhi 1	28.6837	80.9461	119.5
Chitiya Taal	Ghodaghodi 1	28.6661	80.9582	114.2
Dadihawa Sano and Thulo Taal	Nakfaduwa, Ghodaghodi 12	28.5952	80.9084	104.1
Raktahi Ko Taal	Nakfuduwa, Ghodaghodi 12	28.6071	80.9044	95.2
Aithan Chutiya Taal	Ghodaghodi 7	28.6007	80.9381	108.8

Budkauwa Taal	Sariya Bankhet	28.6675	80.9172	126.3
Purbatol Taal	Deukaliya, Ghodaghodi 5	28.6783	80.9134	113.6
Hati Kund and Bhikaiya Twin Lake		28.6819	80.9132	105.1
Bunkaiya Taal		28.6851	80.9145	102.5
Pond/Lake close to highway	Ghodaghodi 5	28.6961	80.9142	118.3
Gothuwa Taal (a)	Ghodaghodi 2	28.6720	80.9786	118.3
Gothuwa Taal (b)	Sandepani, Ghodaghodi 2	28.6715	80.9775	117.6
Chidiya Taal	Sadepani, Ghodaghodi 2	28.6758	80.9764	121.1
Patharpinda Taal	Sandepanni, Ghodaghodi 2	28.6786	80.9792	118.3
Sano Chapad Taal	Belkot, Ghodaghodi 1	28.6785	80.9724	127.8
Gairi Taal	Ghodaghodi 1	28.6790	80.9719	109.8
Chidiyaa Taal	Ghodaghodi 1	28.6793	80.9761	109.4
Chidiya Taal	Ghodaghodi 2	28.6797	80.9754	126.9
Chidiya Taal	Ghodaghodi 1	28.6810	80.9757	123.6
Chidiya Taal	Ghodaghodi 2	28.6837	80.9783	129.9
Kharkhatuwa Taal	Chitalpur, Ghodaghodi 2	28.6832	80.9820	122.2
Wildlife Watering Point	Sikharjhala, Ghodagodhi 9	28.7566	80.8942	130.4
Private Pond (Ram Dular Chaudhary)	Ramkuwa, Ghodagodhi 4	28.7367	80.9460	134.8
Baisawa Taal	Laxmipur, Ghodagodhi 1	28.6966	80.9594	127.7
Budiya Taal	Deepnagar (Dod Khola Pari) Ghodagodhi 8	28.7126	80.9657	134.2
Sun Pokhari	Doda Paari, Ghodagodhi 8	28.7185	80.9701	138.2
Bichki Chootiya Taal	Doda Paari, Ghodagodhi 8	28.7184	80.9692	134.7
Ramfal Taal	Doda Paari, Ghodagodhi 8	28.7183	80.9676	138.6
Ojuwa Taal	Ghodagodhi 1	28.6833	80.9506	119.5
Gurahi Taal	Banbasa, Ghodaghodi	28.6128	80.9046	114.1
Private Pond	Kirtipur, Ghodaghodi 7	28.6181	80.9450	99.5
Private Fish Pond	Rajipur, Ghodaghodi 5	28.6319	80.9331	103.2
Private Pond	Syaukolia, Ghodaghodi 5	28.6477	80.9170	106.5
Private Fish Pond	Chitalpur, Ghodaghodi 2	28.6804	80.9812	120.7

The ponds and lakes in the area form water bodies for birds and wildlife. People in the area traditionally used them for dry season irrigation, catch fishery and watering, harvesting water vegetation and wallowing their farm animals in the summer months. They channelized overflowing water from spillway to irrigate adjoining farm ponds. They also succeeded to obtain support from government agencies and development organizations to construct gated sluices to regulate controlled release of water for irrigation uses. Such gated structures developed for downstream irrigation use were identified in many ponds/lakes, which included Lakthahawa Tal, Kamal Pokhari and Ghodaghodi lake complex.

Many of these ponds/lakes are subjected to increasing human encroachment, except those located deep in the forest and those which are protected water bodies (e.g. Ghodaghodi lakes complex). Human encroachment in the ponds/lakes in the area have particularly intensified over last decade with these contracted out for culture fishery by the municipalities and forest user groups. The contactors have been involved in excavating the ponds and constructing bunds surrounding them, using machines earthwork, to expand the water storage area and depth. These changes brought to the natural formation of the ponds have altered the surface and groundwater flow processes, consequently dry season storage has diminished (see Box 4). Also, the contactors often drain out the water to harvest the fish. This practice has also reduced the volume of water remaining in the storage year round, which diminishes the opportunity of groundwater recharge. The fishery use of the ponds has though produced economic incentive to the people (contractors) and also become important source of revenue for the local government, this has essentially promoted extractive use of the ponds and water in the storage.

Box 4: Effect of Machine Excavation on Water Bodies

Machine excavation and the construction of artificial embankments around naturally occurring lakes and ponds in the Kandara and Kateni sub-watersheds disrupt the delicate balance that sustains these water bodies. These wetlands depend on seasonal surface runoff, lateral inflow from small streams, and the sub-surface seepage from shallow alluvial aquifers recharged by rainfall in the headwater. Mechanical excavation often cuts into natural inlet and outlet channels, altering flow gradients and preventing the slow, diffuse inflow that maintains water levels. Similarly, raised earthen banks block lateral overland flow and seal natural recharge zones, reducing the hydraulic connectivity between ponds and the surrounding aquifer. Over time, restricted inflow combined with enhanced evaporation and sediment deposition causes ponds to shrink, dry earlier in the season, or convert into stagnant, degraded pools. In landscapes of Kandara and Kateni, characterized by micro-topography, high water tables and channel-shift dynamics which have been responsible for the formation of the water bodies in the area, such interventions can rapidly degrade once-productive wetlands and reduce local water storage capacity.

The ponds in the area are also partly silted, shrinking their spread area, depth and volume. People in the area revealed that with the growth in the human settlements, construction of roads and other infrastructures and increase in the mining of riverbed sediments in the upstream areas, the sediment inflow in the ponds in the monsoon season has increased, which has been responsible to accelerate the siltation in the ponds. As stated earlier, the construction of bunds by the pond contractors have led to blocking the inflow and outflow channels. All these changes have been responsible to degrade the pond and undermine their environmental services.

4.1.4 Irrigation Canals

A number of irrigation canals developed and used by the people to irrigate their crops, utilizing the streams and spring sources and lakes/ponds in the two watersheds, inventoried in the study are provided in Table 4.4. The irrigation systems existing in the area are essentially community built canal systems, called farmer managed irrigation systems-FMIS, developed by the people in the area to meet their irrigation needs. Many of these irrigation systems succeeded obtaining support for rehabilitation and modernization of infrastructure and services under irrigation sector development program of GoN at different times. Also, a number of these continue to use traditional brush-wood diversion structures and rudimentary canal systems developed and maintained by the people. Two irrigation development programs that had been instrumental in providing rehabilitation and modernization support to a number of FMISs in the two sub-watersheds are Irrigation and Water Resources Management Project (IWRMP) implemented over the period 2008-2018 and Community Irrigation Project (CIP) implemented over the period 2011-2018 by Department of Irrigation (DoI), GoN.

The study area has rich tradition of *Tharu* community in developing and maintaining irrigation canals to be able to grow rice in the monsoon. In fact, in each *Tharu* village one could identify irrigation canal of some form utilizing the local water sources prior to 1970s. These were all community managed irrigation systems developed and managed by the people collectively. A strong collective action institution was in place to organize and manage development, operation and management of the canal system. Many of these community irrigation systems however vanished over time with the advent of shallow tube-wells and use of centrifugal pumps to pump water directly from streams, ponds and similar water bodies. These two technologies, which were affordable by the people, enabled privatization of irrigation that led to weakening the traditional collective action institutions. Also, with the growth in the human settlement and loss of forest cover, people in the area faced increasing difficulty obtaining brushwood for the construction of diversion structure and repairing them after every flood damage in the monsoon. Tedhi Irrigation System and Gurgi irrigation System, using Kateni River as source, were two comparatively larger community irrigation systems providing irrigation to Tharu villages in the area. Historical context of these two irrigation systems based on the recalls of elderly persons who are the community leaders is provided in the Box- 4 below.

Box 4: Tharu Tradition in Developing and Maintaining FMISs

Tharu community of Kailali and in other parts of the country has long maintained a rich tradition of collective action that underpins the development and sustainability of their farmer-managed irrigation systems. Rooted in customary norms of cooperation, shared labour (jharahi- all able men obliged to contribute free labour) and water sharing arrangements, these institutions enabled Tharu households to organize the construction, maintenance and equitable operation of local irrigation networks. Decision-making was guided by Zamindars, respected elders and canal leaders *(Bhalmansa)* who coordinated water allocation, settled disputes and ensured timely upkeep before planting seasons.

Contd…

The Decision-making was guided by respected elders and canal leaders who coordinated water allocation, settled disputes and ensured timely upkeep before planting seasons. This indigenous governance structure, characterized by mutual accountability, assured labour contributions and strong social cohesion, allowed the Tharu community to manage complex hydraulic environments effectively.

4.1.5 Groundwater

The geohydrology of the Kandara and Kateni sub-watersheds is shaped by their position between the Chure foothills to the north and the expansive alluvial formation of Terai to the south. This transitional setting creates a highly diverse hydrogeological environment that supports a broad range of groundwater systems, from small perched aquifers feeding springs in the uplands to extensive, multi-layered aquifers underlying the lowland plains. Together, these systems provide significant opportunities for groundwater development and irrigation. Fractured Siwalik bedrock, permeable Bhabar recharge zones and thick and laterally extensive Terai aquifers offers dependable groundwater supply to enable year round irrigation while also complement the dry season flow of the local rivers and streams. However, sustaining these benefits requires protecting recharge areas in the Chure foothills, regulating riverbed extraction and monitoring groundwater levels to prevent depletion of this critical resource.

Following assessmenta of groundwater development and use in the study area is based on the information available from groundwater development office, Agricultural Development Bank and office of the Prime Minster Agricultural Modernization Program, all located at Dhangadhi:

Table 4.4: Irrigation Systems Utilizing Local Water Sources in Kateni and Kandara Sub-Watersheds

Name	Location	Lat	Long	Elevation (m)	Remarks
			Kateni Sub-watershed		
Kailari Municipality					
Intake of Gurgi Irrigation System	Kukurbhukka, Kailari 2	28.6005	80.8092	101.9	Traditional canal system developed by *Tharu* inhabitants of the area; Defunct since 2005-2006 due to damage of the weir section of the intake
Intake of Tedi Irrigation System	Tedi, Kailari 8	28.6386	80.8114	110.3	Originally developed by *Tharu* landlords of the area. Rehabilitated and modernized through IWRMP/DoWRI support in 2015-26.
Gurgi irrigation Cannel Bridge Point	Pawra, Kailari 5	28.5545	80.8156	101.8	
Gauriganga and Mohanyal/Chure Rural Municipality					
Intake of Baluwagadhi Sichai Yojana	Balugadhi, Chure Rural Municipality 4	28.8262	80.8200	335.38	Traditional canal system. Rehabilitated and modernized with the support of Provincial Government through Irrigation Development Division about five years ago, in 2020/2021. NEWA, a national NGO has supported development of a drinking water supply system utilizing a spring source
Drain (draining spring and irrigated area on the upstream)	Bhagwanpur, Gauriganga 9	28.7351	80.8527	128.901	Drainage flow is utilized to irrigated by pumping water to adjoining crop lands

Rajiya Kulo Sichai Yojana	Rajiya, Gauriganga 9	28.7432	80.8562	133.226	Water diverted utilizing local drain which drains upstream spring source to provide irrigation in approx. 40 bigha (27 ha) of crop land in Rajiya
Bhagwanpur Sichai Yojana, water from sirsuriya nala, spring source	Bhagwanpur, Gauriganga 9	28.7401	80.8554	136.348	Traditional irrigation system, developed by people by diverting water from Sursuria Nala, a local drain that drains upstream spring source. Rehabilitated and modernized under CIP about 10 years ago. Provides irrigation in 49 ha (73 bigha) of land where people grow three crops in a year.
Intake point of Ojuwa Tole Irrigation Channel	Ojuwa Tole, Gauriganga 9	28.7478	80.8528	123.237	Brushood diversion from local drain, fed by upstream spring sources. Provides irrigation to 25 bigha, serving 25-30 Hhs
Sunpal Irrigation Drain source sunpaal,irrigation drain to baankhet and mauliya(ward 9 and 7)	Sukumbasi Basti, Gauriganga 9	28.7577	80.8685	159.611	Drainage from upstream Sunpal Irrigation System is drained collected in this drain to provide irrigation to the farmers in Bankhet and Maulia in Ward No. 9 and 8 of Gauriganga Rural Municipality
Maulia Bankhet Sichai Yojana	Maulia and Bankhet Ward No. 7 and 9, Gauriganga	28.8006	80.8814	210.599	Intake located in Kandara Khola at Rajghat. Developed with provincial government support about 5 years ago to provide irrigation in more than 150 bigha of land Ward Nos. 7, 8 and 9 of Gauriganga. The canal system is lined.
Kandra Sub-Watershed					
Bhajani Municipality					
Irrigation/ Kanda Khola Sichai Yojana	Mantri Phanta, Bhajani 3	28.4779	80.9906	88.3	The Canal system draws water from Kanda Khola, provides irrigation to more than 1000 ha in Ward 1,2,3 of Bhajani Municipalitiy. Drainage water from the area is fed to Rapti

					Khola which is also source of irrigation in the downstream areas.
Raapti Khola Canal Branch	Theki, Bhajani 3	28.4795	80.9838	86.7	Collects runoff and drainage water from Kanda Khola Canal system and serves irrigation needs of farmers in the downstream areas
Laukaha-Bhaukaha Lake Drain	Jhaljhalia, Bhajani 4	28.5626	80.9394	94.5	Drains overflow of Laiukaha-Bhaukaha Lake to provide irrigation to the farmers in the downstream areas in Bijulia
Nukli Taal Drain	Ganjahuwa, Bhajani 9	28.5386	80.9244	90.7	Drains overflow from Nukli Taal to provide irrigation to the adjoining farmers.
Irrigationn Intake Didi Bahini taal irrigation intake	Bhuruwa, Bhajani 9	28.4909	80.9322	87.1	Sluice gate in the lake used to make regulated release of water for irrigation use, on demand by the farmers
Ghodaghodi Municipality					
Gaidakhera Irrigation System	Gaidakhera, Ghodagodhi ward 4	28.7349	80.9633	134.9	Betani is a spring source which has been traditionally utilized by the farmers in Gaidakhera, Maghi and Sinthari to provide irrigation in over 250 ha of crop land. The traditional system was modernized with CIP support about in 2072-73 B.S. Water from this source also feeds into Nakhrot and Ghodaghodi Lake
Jadai Nadi irrigation System	Rampuir, Ghodagodhi 4	28.7388	80.9432	132.4	Utilizes local spring fed stream to provide irrigation in more than 500 bigha (333 ha) of land in Rampur and Gaushpur. Support of CIP in developing permanent intake

Bhul Bhule Paani Muhan	Rampur, Ghodagodhi 4	28.7379	80.9470	134.2	Spring Source used for mainly irrigation in the past but nowadays due to installation of deep boring widely the command area decreases.
Bagghaili Sichai Yojana	Batulichaur, Ghodagodhi 4	28.7203	80.9642	120.9	Permanent intake structure developed in a spring fed drain from Betani. Canal system feeds Nakhrot Taal and Ghodagodi Taal and also provides irrigation to more than 275 ha of land in Godaghodi, Kailashpur, Kauwa villages located downstream of Ghodaghodi lake
Ghodagodhi Taal outlet	Ghodagodhi 1	28.6837	80.9465	122.8	Overflow from lake utilized for irrigation by the downstream farmers
Ojuwa Taal Outlet		28.6835	80.9495	120.2	Overflow from the lake is collected in a drain, utilized for irrigation in the downstream area
Hati Kunda Deep Well	Deukoliya, Ghodhaghodi 5	28.6824	80.9128	114.9	This more than 600 ft (182 m) deep tube-well system is developed to feed the lake and also provide irrigation to downstream the users in the neighbouring areas

i. Groundwater development in the Kandara and Kateni sub-watersheds has accelerated markedly over the past four decades, transforming the water-access landscape for both irrigation and domestic uses. Prior to the 1980s, most households in the region relied on dug wells, river lifting, or seasonal canal flows, while agriculture remained largely rain-fed or dependent on small traditional surface irrigation systems. As the Terai aquifers became better understood and drilling technologies became available, in the period after 1980s, the installation of shallow tube-wells (STWs) increased steadily. In the early phase, these wells were introduced primarily through donor-supported irrigation programs and government initiatives aimed at expanding dry-season food production.

ii. Farmers rapidly adopted STWs due to their low cost, high reliability, and suitability for small landholdings size. By the 2000s, groundwater irrigation had become the dominant source of water for winter and spring cropping in Bhajani, Kailari, Ghodaghodi, and the surrounding municipalities. Shallow tube-wells, typically 15 to 30 m deep, proliferated across the agricultural belt. Today, in the broader Kandara–Kateni area, several hundred shallow tube-wells are in operation, many owned privately by smallholder farmers and used to irrigate paddy, wheat, vegetables and fodder crops. The relatively high water table and coarse alluvial deposits have made these wells both feasible and productive.

Deep tube-well (DTW) development began later, primarily to support community-based or larger command-area irrigation schemes. These wells, often 80 to 150 meters deep, penetrate more confined aquifers with higher yields, enabling multi-season irrigation for larger blocks of farmland. Over the last decade, provincial and federal irrigation programs have installed dozens of deep tube-wells across Kailali District, including within or adjacent to the Kandara and Kateni sub-watersheds. Deep wells also increasingly supplement drinking-water systems, particularly where demand is growing or shallow wells show declining reliability. An inventory of deep tube-wells developed in the two watersheds for irrigation and domestic water supply is provided in table 4.5.

Table 4.5: Inventory of Deep Tube-Wells for Irrigation and Drinking Water in the Area

Element Name	Location	Lat	Long	Elevation (m)
Kateni Sub-Watershed				
Gauriganga Municipality				
Deep Boring (Irrigation)	Milanchowk, Gauriganga 5	28.7602	80.8059	127.2
Deep Boring (Water supply)	Gauriganga 5	28.7656	80.8147	154.5
Deep Boring (Irrigation)	Jodi Pokhari	28.7315	80.8594	133.6
Deep Boring (Irrigation)	Basanta tole, Ward 8	28.7449	80.8408	135.7
Deep Boring (Water Supply)	Mahadeva, Gauriganga 7	28.7446	80.8403	140.5
Deep Boring (Irrigation)	Manakapur	28.7635	80.8465	144.3
Deep Boring (Irrigation)		28.7393	80.8272	130.9
Deep Boring (Irrigation)	Perahani, Gauriganga 11	28.7067	80.8455	128.4
Deep Boring (Irrigation)	Ward No. 9	28.6744	80.8286	108.3
Deep Boring (Water Supply)	Jhanjhatpur	28.6583	80.8220	99.0
Deep Boring (Irrigation)	Gauriganga 11	28.6917	80.8450	120.9

Kandara Sub-Watershed				
Bhajani Municipality				
Deep Boring (Water Supply)	Jawalpur, Bhajani 3	28.4668	80.9867	83.3
Deep Boring (Irrigation)	Kanhaiyapur, Bhajani 3	28.4663	80.9973	85.2
Deep Boring (Irrigation)	Dhusigaun, Bhajani 3	28.4924	81.0012	86.5
Deep Boring (Water Supply)	Khailad, Bhajani 4	28.5295	80.9423	88.0
Deep Boring (Water Supply)	Bhuruwa, Bhajani 9	28.4938	80.9299	93.6
Ghodaghodi Municipality				
Deep Boring (Irrigation)	Magar Tol, Ghodagodhi 9	28.7584	80.9017	137.0
Deep Boring (Water Supply)	Pichkapur, Ghodagodhi 9	28.7500	80.9041	130.0
Deep Boring (Irrigation)	Deepnagar, Ghodagodhi 8	28.7104	80.9682	132.8
Deep Boring (Irrigation)	Batulichaur, Ghodagodhi 4	28.7176	80.9620	126.1
Deep Boring (Irrigation)	Tribeni bazaar, Nakkhuduwa	28.6131	80.9088	92.6
Deep Boring (Water Supply)	Saraiya Bankhet	28.6675	80.9169	124.7
Deep Boring (Water Supply)	Faram Ramgadh, Ghodagodhi 9	28.7527	80.9215	124.4
Deep Boring (Water Supply)	Rampur, Ghodagodhi 4	28.7403	80.9514	135.7
Deep Boring (Water Supply)	Sandepani, Ghodaghodi 2	28.6720	80.9795	101.7
Deep Boring (Water Supply)	Dhanaura	28.5295	80.9423	88
Deep Boring	Bhuruwa	28.4938	80.9299	93.6

Signs of localized groundwater stress have started emerging over last decade. Farmers in some areas of Kailari and Bajani revealed that some shallow tube-wells go dry in the dry season, indicating gradual lowering of the shallow water table in the area. In pockets where shallow tube-well density is very high, discharge rates have reduced compared to earlier years. Seasonal monitoring by municipal and water-user groups also suggests that post-monsoon groundwater recovery is becoming slower, likely due to increased extraction combined with reduced recharge from degraded Chure foothills and declining floodplain infiltration. Although the deeper confined aquifers remain productive, there is growing concern that continued expansion of both shallow and deep tube-wells without management could lead to long-term depletion.

4.2 Comparative Analysis of Kandara and Kateni Sub-Watersheds

The Kateni and Kandara sub-watersheds, although geographically adjacent and hydrologically interconnected within the larger Mohana basin, exhibit distinct characteristics in their water sources, flow regimes, and levels of emerging stresses. These differences arise from variations in geomorphology, settlement patterns, groundwater dependence and exposure to environmental change. A comparative understanding of these systems is essential in informing appropriate nature-based solutions and governance interventions.

Surface water systems form the backbone of both the sub-watersheds, but their dynamics differ significantly. The Kandara watershed is shaped by the larger and more dynamic Kandara River, which carries heavy monsoon flows from the Siwalik foothills into the Terai plains. Its hydrological behaviour is strongly influenced by channel migration, sediment deposition and flashy monsoon surges. Flood events in Kandara's downstream reaches, particularly in Bhajani, have intensified in recent years due to increased sediment load, reduced channel conveyance, and encroachment into floodplains. By contrast, Kateni sub-watershed is fed by comparatively smaller tributaries, including the Kateni River, which show less dramatic but still significant seasonal fluctuations. While both systems experience monsoon peak flows and low dry-season discharges, Kandara's larger catchment and greater erosive power produce more extensive flood impacts and higher sediment loads, thereby exerting greater stress on riverine ecosystems and dependent communities.

Groundwater systems provide the most reliable year-round water source across both watersheds, yet the nature of groundwater use and emerging pressures differs. In the Terai plains of both watersheds, shallow unconfined aquifers support widespread use of shallow tube-wells for irrigation and domestic water supply. However, Kandara's downstream areas, characterized by denser agricultural settlement and higher cropping intensity, has more rapid proliferation of shallow tube-wells and deeper wells. The resulting concentrated extraction is creating localized declines in shallow water tables, particularly during late winter. Kateni, with slightly lower settlement density and more dispersed agriculture in its mid-reaches, faces similar trends but with slower onset. Nevertheless, the shared Bhabar recharge zone that feeds aquifers in the both the sub-watersheds is under pressure from land-use change and declining infiltration capacity due to Chure degradation.

Springs and headwater sources also show divergent patterns. In Kateni's upland zones, small perennial and seasonal springs form important community water sources, although many show reduced discharge during prolonged dry spells. Kandara, with more disturbed upper catchments and higher rates of road cutting and erosion, exhibits greater spring fragility. This contrast illustrates how land-use pressures in upstream Siwalik zones translate into differing levels of headwater depletion and reduced base flows in the two watersheds.

Both watersheds host diverse wetlands, ponds, and marshy depressions, particularly in Ghodaghodi and Bhajani areas. Yet the Kateni sub-watershed, being closer to the Ghodaghodi lake complex, contains more ecologically intact wetland patches. The Kandara watershed, by contrast, has seen more rapid conversion of ponds into fish ponds, farmland, or settlement, leading to shrinking wetland extent. Such changes diminish groundwater recharge surfaces and reduce the buffering capacity of the landscape against both drought and floods.

Across both landscapes, a common set of stresses is emerging: increased climatic variability, rising extraction pressure, sedimentation, and changing land use. However, these stresses manifest more acutely in the Kandara sub-watershed, where larger river systems, denser groundwater development, faster wetland loss, and intensifying flood hazards create a more fragile hydrological balance. Kateni faces similar risks, but with comparatively higher remaining ecological integrity and slightly lower extraction intensity, conditions that may escalate if the current trends continue.

5. Institutions, Local Knowledge and Management Practices

5.1 General

Water management in the Kandara and Kateni sub-watersheds is shaped by the interplay of climate, hydrology, social practices, and the institutional arrangements governing water sources and systems. Springs emerging from the Siwalik foothills, stream sources bringing water and sediments from upstream to downstream areas and feeding the irrigation canals, water bodies and groundwater, ponds and wetlands that retain water for diverse uses and the extensive groundwater systems of the Terai available for irrigation and domestic uses, all constitute critical water sources. These sources support domestic water use, irrigation, livestock, fishery and wetland-based livelihoods, while also modulate flood risk and support important ecological functions. Yet their health and sustainability depend not only on natural processes but also on how local institutions regulate extraction, how communities draw upon their local knowledge and practices and how management practices evolve under changing socio-economic pressures. Understanding these three domains together, institutions, local knowledge, and management practices, is essential for developing realistic, grounded and people-centred NbS for conservation, restoration and management of water sources and systems in the two sub-watersheds.

5.2 Institutional Landscape in Water Governance

5.2.1 Policies and Legal Provisions

Nepal's transition to federalism has fundamentally reshaped the governance of natural resources but ambiguities in constitutional and statutory provisions continue to generate overlapping claims over the ownership and management of water sources and water bodies. The Constitution of Nepal (2015) assigns water governance across all three tiers of government: the federal government holds authority over large-scale projects, transboundary waters and formulation of national water policy; provincial governments are mandated to develop provincial water resource strategies, irrigation systems up to certain scales and river training works; while local governments have explicit jurisdiction over local water supply, irrigation canals, watershed protection, and small-scale river systems as per Schedule 8. Furthermore, the Constitution's Schedule 9 lists water resources management as a concurrent responsibility, requiring all three tiers to collaborate in the management of water resources and maintaining their health. This provision intends to foster cooperative federalism but one that has, in practice, produced jurisdictional ambiguity.

This ambiguity is most visible in the governance of ponds, lakes, wetlands, and spring sources located within forest areas. The Forest Act (2019) and earlier forest policies clearly state that any water body located inside national, community, or leasehold forests falls under the control and management authority of the Forest Department and its subordinate bodies. Forest Division Offices therefore assert legal jurisdiction over ponds and lakes on the ground that these link to forest ecosystem. In contrast, local governments interpret their constitutional mandate over local water supply, watershed protection, local irrigation and natural resource management as conferring authority to manage all water bodies within their territorial boundaries, including those situated inside forests. As local governments increasingly invest in fishery promotion, pond restoration, development and rehabilitation/restoration of canal and drainage systems utilizing these wetlands and tourism-based activities, the question on who owns and controls ponds and lakes located in the forest area has become politically contested.

These overlapping mandates have produced practical conflicts: local governments claim revenue rights from wetland-based enterprises while Forest Division Office emphasizes ecological protection and national-level custodianship. The communities find themselves caught between two competing authorities. The absence of a harmonized federal law defining water-body jurisdiction under the new federal order has further intensified the issue. This contestation is especially relevant in the Kandara and Kateni sub-watersheds, where ponds and wetlands lie within community and national forest tracts. Resolving these conflicts requires developing co-management frameworks, harmonizing forest and water resource laws, and clarifying jurisdiction through bilateral agreements between Forest Offices and local governments. Without such clarification, governance fragmentation will continue to undermine effective conservation and sustainable use of the sub-watersheds' water systems.

5.2.2 Roles and Responsibilities of Local Governments

Under the Local Government Operation Act (2017), local governments in the study area hold primary responsibility on the management of water sources and systems within their jurisdictions. These responsibilities include the construction and maintenance of local irrigation canals, development and management of drinking water schemes, protection of water sources and disaster risk reduction at the local level. In principle local governments are expected to function as custodians of local level water and other natural resources. In practice, however, municipalities have been largely involved in the construction of physical infrastructures and systems and contracting out ponds and lakes and extraction of riverbed aggregates for revenue generation. Their roles in the accounting and monitoring the health of water sources and system and proactively rolling conservation and management activities are essentially limited.

Also, despite formal mandates to function as custodian and regulator of local water sources and systems, the capacities vary widely. For example, downstream municipalities like Bhajani and Kailari face recurrent flooding and canal breaches yet these lack the technical and financial resources to undertake comprehensive river training or spring conservation programs. Upstream local governments, such as Mohanyal and Chure Rural Municipalities, hold key recharge zones but have limited technical and financial resources and qualified human resources to roll watershed and spring-shed management programs. In fact, much of their roles limit to addressing existing administrative, livelihoods and infrastructure challenges on day-to-day bases with little attention delivered towards conservation and management of natural resources. This mismatch between legislative authority and actual capacity restraining them is a recurring in the area.

5.2.3 Community Based Water Institutions

Community developed irrigation systems (FMIS) existing in the area have historically played key role in developing, expanding and sustaining irrigated agricultural system in the study area. Many of these systems utilize traditional brushwood diversion structures and earthen canal systems to draw water from Kateni and Kandara streams. There are also FMISs which are utilize existing lakes and springs as water source. Some of these irrigation systems have also succeeded obtaining external support, mainly from sectoral irrigation development programs such as IWRMP and CIP, used towards construction of permanent diversion structure and improvement in the canal system and control structures at critical points with the aim to improve the efficiency and reliability of irrigation. A strong organization of users undertaking their annual construction, canal cleaning and regular and emergency repair and maintenance and mobilizing resources for these works is central to sustained functioning of the FMISs in the area. *Tharu* community in the area has rich tradition of devising self-governing water institutions (see Box) and the institutional arrangement that we see in many of the FMISs in the area draws on this tradition. However, with the increasing groundwater pumping for private use, which has been possible with the development of shallow tube-wells and use of diesel and electricity driven centrifugal and submersible pumps in the area, the local irrigation organizations have weakened. Key informants in the area revealed that instead of mobilizing labour resource many times in air required for repair and maintenance in traditional FMIS utilizing brushwood and rudimentary canal system, people prefer to invest in their own shallow tube-well to draw groundwater more conveniently and at will. Another change noted in the irrigation institution related to formalizing of organization-- those FMISs that received rehabilitation and modernization support under irrigation development programs of GoN were required to register the organization in the irrigation development agencies for statutory status of water users' organization. Therefore, at present both formal and informal user organizations exist in the area.

Another change with regards to evolution of water institution relates to development of community based water supply system in the area-- several gravity flow and groundwater pumping based piped water supply systems have been developed in the study area in the recent years with financial support from different sources and in each of them Drinking Water Supply and Sanitation User Groups have been constituted to organize and manage distribution of drinking water supply among the users and collection of water tariffs. Similarly, a wetland user group has evolved in Ghodaghodi lake, where fish cooperatives and wetland conservation committees regulate access, enforce seasonal fishing bans, and manage invasive weeds. In upland settlements in Mohanyal, spring user groups informally enforce cleanliness around springheads, restrict washing or livestock access and occasionally coordinate protection works.

The *Tharu* community of the area played a central role as custodians of local water sources and natural resources. Traditionally, Tharu settlements were organized around *khet* (irrigated fields), *bari* (upland farms), and communal forests, with water sources—*pokharis* (ponds), *jhoras* (springs), *ghols* (seasonal wetlands), and river-fed canals—managed collectively through customary norms. Tharu households participated in collective desilting of canals before monsoon, cleared inflow channels to ponds, removed silt from the ponds/lakes to maintain their recharge function, protected wetland vegetation used for thatching and maintained sacred groves and ponds believed to house ancestral or protective spirits. Many ponds in Kailari and Bhajani bear names tied to *Tharu* clans or deities, reflecting a cultural sense of ownership and stewardship. People in the area revealed that *Tharu* B*halmansa* (village elders) allocated water turns, enforced restrictions on cutting riparian vegetation, and regulated access to communal wetlands for fishing, livestock grazing and reed collection. This custodianship was rooted in reciprocity—communities protected water bodies, and in turn, water obtained sustained farming, fisheries and cultural life.

However, this tradition has weakened significantly over the past four decades due to land dispossession, in-migration, weakening of traditional authority structures, and the transition to formal state-managed systems. The shift from communal to individualized land ownership reduced collective responsibility for canals and ponds. Large-scale migration into Kailali after the 1960s resettlement program introduced new land-use practices and disrupted customary *Tharu* governance. The expansion of modern irrigation, proliferation of private tube-wells, and introduction of commercial fish farming replaced communal pond management with individualized economic interests. *Tharu* youth outmigration and the erosion of *Bhalmansa*-based village leadership further undermined traditional norms. Ponds and lakes once maintained jointly by *Tharu* communities are now heavily silted, encroached or converted to private fisheries, and spring protection practices have diminished as reliance on piped water and groundwater has increased. These shifts have contributed to the fragmentation of custodianship and weakened the community’s traditional ecological knowledge systems.

5.2.3 Formal Government Agencies

Several formal government agencies at the federal and provincial levels play important roles in the conservation and management of water and natural resources in the Kandara and Kateni sub-watersheds, although their mandates frequently overlap with those of local governments. At the federal level, the most visible actor is the President Chure–Terai Madhesh Conservation Development Board (PCTMCDB), established to protect the fragile Siwalik (Chure) hills and downstream recharge zones. The Board operates programs in Mohanyal, Gauriganga and Ghodaghodi and Kailari municipalities, focusing on slope stabilization, gully control, watershed protection, river training, and sediment management. Its interventions, such as bioengineering works, community-based forest restoration, and check-dam construction, directly shape the hydrological health of springs, streams and groundwater systems in the study area. The Department of Forests and Soil Conservation, through the Forest Division Offices (FDOs) in Kailali, also exercises strong authority over forested catchments, ponds, wetlands and lakes located within national and community forests. In parallel, the Irrigation Division Office of Provincial Government (under Ministry of Physical Infrastructure Development of Sudurpaschhim Province) Department of Water Resources and Irrigation (under federal Ministry of Energy, Water Resources and Irrigation) implement deep tube-wells, canals, and river training structures in the Terai portions of the watersheds. At the provincial level, the Sudurpashchim Ministry of Industry, Tourism, Forests and Environment, the Provincial Forest Directorate, and the Provincial Water Resources and Energy Directorate are responsible for managing provincial forests, river systems, and medium-scale irrigation infrastructure.

Although these institutions maintain formal coordination channels with local governments, typically through joint planning meetings, participation in municipal sector committees, co-financing of watershed restoration projects, and technical approval processes, coordination among them remains largely procedural rather than substantive. In many cases, line agencies implement projects independently, informing local governments only after plans have been finalized. This top-down approach, combined with ambiguities in the Constitution's division of powers, contributes to overlapping authority. For example, while the Forest Act places all water bodies within forest areas under the jurisdiction of the Forest Department, local governments claim constitutional authority over local water resources regardless of land category. Similarly, both the Chure Board and local governments pursue river training, pond restoration and spring protection activities, often without shared ecological baselines or harmonized priorities. These overlapping mandates dilute accountability, create confusion over ownership and revenue rights and result in fragmented project implementation. As a consequence, conservation and restoration efforts, especially those requiring watershed-scale coherence, are weakened, leading to piecemeal interventions that fall short of addressing the systemic drivers of degradation in the two sub-watersheds.

5.2.3 Inter-Institutional Coordination

Despite multiple water institutions operating in the two watersheds, coordination among them remains weak. Upstream–downstream linkages are poorly addressed, even though upstream land use in the Chure foothills directly affects spring discharge, flood peaks and sedimentation downstream. Irrigation, forestry, agriculture and disaster units operate largely independently, resulting in fragmented management of rivers and wetlands

Flooding and flood damage along Kateni and Kandara Rivers is known to be exacerbated by sand-mining and riverbed extraction—issues overseen by municipal planning offices but rarely coordinated with irrigation institutions who depend on stable river intakes. Similarly, groundwater development is largely unregulated because no agency has clear enforcement authority, even though tube-wells receive public funds from agriculture or irrigation offices. These coordination gaps undermine the sustainability of water systems and limit the effective implementation of nature-based solutions.

When the municipality functionaries were asked on the kind of coordination and sharing/exchange of information they have been maintaining among the upstream and downstream municipalities, they narrated so such formal mechanism is place at present. Nonetheless, they identified the need for such coordination and exchange of information given hydrologically interconnected water sources and systems in the area. These observations from the area clearly reveal that inter-agency coordination mechanism is weakly placed and challenging.

5.3 Local Knowledge and Management Practices

Local knowledge and management practices explored and documented in the course of this study and their relevance and the possibilities of packaging them with the NbS are detailed in the following sections.

5.3.1 Local Knowledge and Management Practices of Springs

In the Siwalik foothills of Mohanyal Rural Municipality, communities have long relied on springs emerging from fractured sandstone layers. Local households possessed detailed knowledge of which slopes recharge specific springs, often pointing to wooded patches or areas with deep leaf litter as the "mother places" (*srot thau*) that sustain year-round discharge. People also indicated that drying of moss patches, reduced dampness on rock faces and weakened trickle flow during Chaitra-Baisakh (March-April) are indicators of weakening of springs. They inferred that deforestation or new road cuts have disrupted infiltration pathways which has been responsible for drying and depletion of many spring sources in the area. Traditional management practices identified by them included vegetated fencing of the springheads, clearing debris from *kuwas* (spring mouth/chambers), and restricting livestock access. However, such practices are weakening as outmigration reduces communal labour force.

5.3.2 Local Knowledge and Practices on Ponds and Lakes

Across the southern Terai plains, in Bhajani, Ghodaghodi, and Kailari municipalities, communities traditionally managed ponds and lakes and wetland depressions (*ghols*) as multiple use water bodies for irrigation, livestock watering, domestic uses and cultural functions. Local knowledge guided seasonal desilting, usually carried out after the monsoon when ponds would be filled with sediment-householders collected silt to spread on croplands to improve soil fertility or used the mud to plaster their wooden houses. In Ghodaghodi Municipality, *Tharu* communities historically an emergent vegetation like Typha and reeds to maintain open water habitats and prevent mosquito proliferation. Ponds such as Kamal Pokhari in Kailari once underwent annual community led clearing of inflow channels to ensure monsoon replenishment. With increasing conversion of ponds and lakes into private fishery, contracted out to entrepreneurs, however, communal desilting and maintain the vegetation growth has declined. Many ponds now suffer from thick weed mats and sedimentation. In the Ghodaghodi Lake Complex, user groups continue to practice seasonal weed removal and enforce fishery bans, but smaller village ponds lack similar custodianship.

5.3.3 Local Knowledge and Management Practices on Stream Sources

Local farmers and fisher groups living along Kandara, Kateni and Mohana Rivers could reveal their intimate understanding on monsoon hydrology and channel behaviour of these streams. They could identify flood-prone reaches, such as the eastern embankment near Bhajani Ward 1 where the Kandara often breaches, and knew which stretches accumulate heavy sediment after intense storms.

Traditional canal intakes were historically placed based on such knowledge, often aligned with natural pools or gentle bends where flows were predictable. Communities also understood the risks of placing intakes too close to unstable banks. For instance, farmers in Gurgi Irrigation System in Kailari recalled adjusting the location of their traditional intake along the Kateni river every few years due to channel shifts. Although these insights persist, fewer households today engage in river watching or collective canal adjustment because access to shallow tube-well has reduced reliance on river-fed systems.

5.3.4 Local Knowledge and Management Practices on Food Protection and Restoration

Community-led flood protection in Bhajani and Kailari historically combined local level observation and collective action in the events of floods. Communities recognized early flood indicators, such as rapid water discoloration, swiftly rising flow velocity and inflow of floating debris, and prepared temporary embankments using brushwood, bamboo, and sand-filled sacks. Residents of Bhajani recollected mobilizing overnight to reinforce banks when the Kandara swelled during major monsoon of 2013 and 2021. People believed that floodwaters should be “given space” (*paani lai goj dinu parchha*), which shaped earlier practices of keeping seasonal floodplains open for overflow, a traditional approach to flood mitigation. After floods, communities restored damaged fields by spreading deposited silt or clearing sand cast manually. Today, however, floodplain encroachment, rising dependence on engineered embankments and conversion of open areas into settlement or agriculture have weakened these traditional protective practices, resulting in greater vulnerability during large floods.

5.3.5 Local Knowledge and Practices of Management of Sedimentation in Lakes and Springs

Sedimentation is widely recognized by local communities as a key factor reducing the depth and functionality of streams, ponds, and lakes. People in both the sub-watersheds understood that heavy monsoon rains washing soil from deforested Siwalik slopes accelerate sediment inflow to the Kandara and Kateni rivers and numerous water bodies in the area. Historically, they practiced small-scale sediment control-- maintaining vegetated riverbanks, leaving belts of kans grass (*Saccharum spontaneum*) along stream edges to trap silt and constructing small brushwood barriers in feeder gullies. In Kailari, people recalled using “jhankri bandhs”, temporary brushwood check-structures, to to slow runoff from farm lands to reduce the sediment loads entering the ponds. In Ghodaghodi’s wetland peripheries, *Tharu* groups traditionally cut and removed overgrown reeds to prevent excessive organic silt accumulation. However, with expanding road networks, sand mining, and reduced communal labour, natural sediment-trapping practices of the community has weakened.

5.4 Key Takeaways to Designing and Promoting NbS on Water Sources and Systems

The analysis of local institutions, knowledge systems and community management practices across Kandara and Kateni sub-watersheds illustrate that water governance in the area is shaped by deeply rooted hydrological understanding, traditional stewardship norms, shifting socio-economic conditions and fragmented institutional mandates. While communities still retain intimate knowledge of spring recharge areas, river behaviour, pond ecology, and sediment dynamics, the collective practices that historically maintained these systems are weakening due to outmigration, expansion of area under private tube-wells, land-use changes and reduced communal labour. At the same time, overlapping responsibilities among Forest Offices, local governments, and provincial agencies generate institutional confusion that undermines watershed-scale conservation efforts. These insights underscore that NbS interventions must be designed to revive local custodianship, strengthen cross-scale institutional coordination and work with, rather than replace, the ecological processes and traditional practices that once sustained water systems in the two sub-watersheds. Following takeaways can be made from the understanding of institutional arrangement and local knowledge and management practices presented in this section with regards to the promotion of NbS for the conservation and restoration of water sources and water bodies in the area:

i. **Local knowledge provides a strong foundation for NbS promotion:** Communities possess precise knowledge of spring recharge zones, flood pathways, sediment hotspots and wetland dynamics. This knowledge would be worth integrated into NbS planning, mapping and prioritization.

ii. **NbS restores and/or complements declining community practices:** Traditional actions, such as fencing of spring-shed, pond desilting, reed management, canal clearing, vegetated bank maintenance, offer low-cost, culturally rooted NbS models that can be revived and scaled.

iii. **Spring-shed protection requires both social and ecological interventions:** Local knowledge of seepage zones and slope behaviour can be used to guide reforestation, contour trenching and bioengineering in the Chure foothills.

iv. **Pond and lake restoration possible with the traditional multiple use functions:** Community desilting, wetland vegetation management and seasonal water retention practices provide a base for NbS that enhance biodiversity and groundwater recharge.

v. **Stream health improvement is possible through restoration of riparian vegetation:** Residents' understanding of erosion-prone banks and channel shifts can guide the placement of bioengineered stabilization structures, vegetative buffers, and floodplain reconnection.

vi. **Flood risk reduction is enhanced through natural floodplain functions:** Local traditions of leaving floodplains open and using natural berms in the streams aligned with NbS strategies helps reduce monsoon peak flows and enhance infiltration.

vii. **Sediment control requires upstream–downstream integration:** Community awareness together with such NbS measures as brushwood check-dams, conservation/establishment of grass belts on the channel bed and banks and gully plugging in feeder tributaries helps controlling sedimentation in the rivers/streams.

viii. **Institutional coordination is essential for NbS success:** Addressing conflicts between Forest Offices and local governments, and harmonizing mandates across agencies, is critical for watershed-scale NbS that spans forest, agricultural and wetland management.

ix. **NbS promotes community stewardship:** Empowering Water User Groups, Wetland User Committees and spring protection groups would ensure long-term sustainability and shared responsibility.

6. Recommended NbS Measures

The hydrological systems of the Kandara and Kateni sub-watersheds, encompassing fragile Chure hill slope spring sources to dynamic floodplain streams, ecologically important ponds and lakes and extensive alluvial aquifers of the Terai, are increasingly stressed by sedimentation, land-use changes, declining recharge and growing extraction pressure. Nature-Based Solutions (NbS) offer a holistic and cost-effective pathway to restore these interconnected water systems by working with ecological processes rather than relying solely on hard infrastructure. The NbS measures recommended in this chapter collectively aim to safeguard the integrity of spring sources through spring-shed protection and catchment rehabilitation; conserve and revitalize ponds and lakes by reducing sediment inflow, restoring wetland buffers and enhancing natural hydrological functions and improvement of stream hydrology and ecology through riparian restoration, bioengineering, sediment control and floodplain reconnection; and strengthen groundwater security through improved monitoring, managed aquifer recharge, pumping regulation, and widespread use of infiltration and recharge pits. Together, these interventions build resilience across the entire watershed, ensuring sustainable water availability, reducing disaster risks restoring ecological balance and supporting the long-term livelihood and environmental well-being of communities in the two watersheds.

6.1 Measures for Spring Source Protection

Spring sources in the Kandara and Kateni sub-watersheds arise predominantly from the fractured Siwalik foothills and the highly permeable Bhabar zone, where groundwater emerges along slope breaks or lithological contacts. The spring sources in the area are highly sensitive to land-use change, extraction of native vegetation cover, haphazard construction of roads and other infrastructure. All these changes produce decline in infiltration and recharge of aquifers feeding into the spring sources. Sustaining the spring flow regime therefore requires interventions that restore natural recharge, stabilise slopes, and maintain the ecological functions of the upland catchments. Following NbS measures would be worth promoting in the area as long-term strategies for spring source conservation and restoration in the area:

i. **Restoration of Forest Cover of Native Vegetation in the Chure Recharge Zones:** Reforestation of degraded hillslopes using native vegetation species (Sissoo, Khair, Semal, and indigenous shrubs) would enhance soil permeability, organic matter content, and root-zone infiltration. In the Chure formations, dominated by fragile sandstone and conglomerate, native vegetation would stabilize quickly, which would reduce erosion and sediment movement that currently suppresses spring discharge. Maintaining vegetative cover helps regulate the timing and magnitude of subsurface flows feeding springs. Assisted Natural Regeneration (ANR), involving regulated grazing and tree/shrub lopping on the degraded hill slope would help regenerate the forest cover in short period of time.

ii. **Micro-Catchment Treatment and Slope Stabilization Measures:** Developing contour trenches and infiltration pits across the upper catchment would slow surface runoff, increase soil moisture, and promote percolation into fractured rock layers that recharge springs. Their effectiveness would be particularly high in Siwalik slopes where intense monsoon rains cause rapid runoff and low infiltration. Alongside, small bio-engineered structures placed in the gullies would trap sediment and increase water residence time. Over time, these would allow infiltration hubs to form, enhancing base flow to nearby springs.

iii. **Spring-Shed Management:** Mapping and physically demarcating the recharge area of key springs and controlling incompatible land uses, such as sand mining, road cutting, and construction that disconnect the recharge–discharge relationship, would promote restoration and rejuvenation of spring recharge zones. Bio-fencing the spring head using bamboo-hedge and thorny shrubs would protect the area and contribute to regenerate and stabilize the soil formation. Protection from livestock trampling, contamination and disturbance helps maintain the ecological integrity of spring heads. Development and restoration of infiltration pits/ponds and stone walls across the slope in the spring heads would delay overland flow and enhance infiltration. All these measures constitute spring-shed management which is recognized globally as foundational NbS. These measures have proven success in Nepal's mid-hills.

iv. **Managing Roads, Trails and Extraction Pressures:** Spring depletion in Chure region is strongly influenced by road cutting, drainage diversion and unregulated sand/gravel extraction, all of which intercept/disturb subsurface water flow paths. NbS measures to manage these extractive pressures in the area would include: a) Following green road principle in the development of roads- avoiding spring recharge zones in fixing road alignment, bioengineering for cut-slope protection and provision of proper drainage outlets; b) developing vegetated buffer along extraction zone to reduce sediment movement; and c) regulated sand/gravel/boulder quarrying and mandatory rehabilitation of disturbed areas.

v. **Community Stewardship:** Community stewardship holds the key to the success of protection and restoration of springs. Therefore, investing on sensitizing and organizing 'friends of springs' involving local community, especially youths, and engaging them in the protection and management of spring recharge area would hold merit. They can be engaged in monitoring the spring flow and controlling extraction in the spring heads.

6.2 Measures for the Conservation and Restoration of Ponds and Lakes

Ponds and lakes in Kandara and Kateni sub-watersheds, ranging from small village ponds to the extensive wetlands such as Ghodaghodi lake complex, constitute critical ecological, hydrological and livelihood assets. They support groundwater recharge, regulate floods, sustain biodiversity and provide water for agriculture, fisheries and domestic use. However, these water bodies face escalating pressures, including sedimentation, invasive weeds, agricultural encroachment, water abstraction and declining catchment health. Evidences from the study area reveal that these natural water bodies in the area are facing immense human pressure, which may be detrimental to their health and existence in the long run. Following NbS solutions are proposed as sustainable, context-appropriate interventions that directly address these stressors:

i. **Watershed Level Sediment Management and Catchment Rehabilitation:** Sedimentation is the single biggest threat to ponds and lakes in the study area, driven by Chure erosion, unregulated road construction and extraction of riverbed aggregates. Following measures promoted in the area would hold merit in controlling sediment inflow into the ponds and lakes: a) Reforestation and assisted natural regeneration in the catchments feeding into the ponds and lakes, especially above Ghodaghodi and in upper reaches of Bhajani annd Kailari where large number of natural ponds and lakes are located; b) Development of bio-engineered check-dams and vegetated silt-traps in upstream gullies to reduce sediment inflow; and c) Restoration of riparian vegetation along inflow channels using native grasses, reeds, bamboo and shrubs to stabilize soils and filter sediment before it reaches the ponds and lakes. These interventions would help reduce siltation rates and extend the functional life of the water bodies.

ii. **Wetland Buffer Creation:** Establishing ecological buffers around ponds and lakes is known to help maintain water quality and hydrologic function. Establishing 20–50 m vegetated buffer strips using native wetland species, such as reed and bamboo would work as bio-fencing and this would also protect against runoff, inflow of chemicals and encroachment. These buffers serve as natural filters, enhance shoreline stability and help maintain ecological integrity.

iii. **Promoting Eco-Hydrological Desilting:** Restoration of ecology and hydrology of the water bodies without involving repeated mechanical excavation, known to destroy wetland habitat and flow path of the springs discharging into the ponds, would be worth promoting. Promoting nature based desilting the water bodies through following measures would hold merit: a) seasonal wetland flushing, allowing excess monsoon flow in the water bodies to enter into designated overflow/flushing channel; b) restoring natural inflow and outflow channels to prevent formation of stagnant zones to cause siltation, c) allowing selective manual desilting in heavily silted/choked areas followed by planting emergent vegetation to stabilize the exposed beds.

iv. **Control and Management of Invasive Aquatic Weeds:** Water hyacinth *(Pontederia crassipes)*, Ipomoea (*Ipomoea aquatica*) and excessive growth of Elephant Grass *(Pennisetum purpureum)* were identified to cause choking of the ponds in Bhajani and Kailari area. Employing/promoting following nature based weed control strategies would hold merit: a) mechanical removal combined with natural control, such as rearing fish species (for example Grass Corps) that consume soft weeds, c) Restoring strip of native plants on the pond edges to compete with invasive plants; and c) Promoting organic farming and control use of chemical fertilizer in the crop areas closed to the wetlands to reduce the nutrient load reaching into the water bodies.

v. **Promoting Groundwater Recharge through Wetland Regeneration:** Ponds and lakes in Terai and Bhabar zone serve as natural recharge hubs, therefore promoting their use as natural bodies for concentrated groundwater recharge would hold merit. This can be promoted through one or more of following measures integrated into restoration of ponds and lakes: a) creating/establishing recharge pits and infiltration galleries in the pond periphery; ii) Incorporating "permeable earthen berms" in the pond embankment to spread water during monsoon and increase soil contact time; c) promoting seasonal (monsoon) water retention in the wetlands in the flood plains without draining them, and d) discouraging emptying/drying the ponds and lakes from November to March for harvest of fish by the fishery contractors, which is currently in practice and causes wastage of stored water without any productive downstream use.

vi. **Integrating Wetlands in the Flood Management Strategies in the Study Area:** Given flood prone nature of the study area and the increase in the incidences of devastating floods in the recent history, it would be useful to integrate the existing water bodies in the flood management strategy of the local and provincial governments. The efforts required to this end would involve: a) sensitizing/educating the local government functionaries that one of the important function of the natural water bodies is to absorb monsoon flow surge and create buffer storage to attenuate the flood peaks- this knowledge/appreciation is currently deficient in the area which would link wetland conservation directly to municipal flood resilience goals.; b) Restoration of floodplain depressions that function as natural sponge in the landscape to buffer flood water and promote groundwater recharge; and c) Promote multifunctional use of existing ponds and lakes, through integration of fishery, tourism/recreation, flood attenuation and groundwater recharge in their use and management.

vii. **Community-Based Conservation and Co-Management of Ponds and Lakes:** Long-term pond and lake restoration in the area would depend heavily on institutionally anchored community stewardship. This can be promoted by constituting wetland user groups involving the communities in their periphery and educating and empowering them to actively participate in the conservation and management of ponds and lakes. It should be in the interest of the local governments, who currently hold the custodianship of the natural water bodies in their jurisdiction to constitute such user groups and actively involved in the monitoring and decision making relating to pond management. Currently, community stewardship is missing in the management of ponds and lakes, which would be worth promoting by the local government with the support from WWF that are working on the conservation and promotion of wetlands in the area.

6.3 Measures for the Improvement of Stream Hydrology and Ecology

Streams in Kandara and Kateni sub-watersheds face complex pressures arising from intense monsoon flows, sediment deposition, encroachment, and poorly functioning traditional irrigation systems. NbS would offer a long-term, low-cost, and ecologically sustainable approach to improve stream health, stabilize the canals and enhance reliability of water abstraction and delivery for agricultural and domestic uses. Following NbS measures would be worth promoting in the area as context-appropriate strategies grounded in local geomorphology and community needs.

i. **Streambank Stabilization Using Bioengineering Measures:** Given high sediment load and unstable banks of Kandara and Kateni and its tributaries, structural-only interventions for stream bank erosion control and bank stabilization would be liable to fail. In this situation bioengineering offers a more resilient alternative. Some of the bioengineering measures that would hold merit in the area include: a) Planting riparian buffer strips of native grasses, reeds, and shrubs that protect banks while filtering pollutants- this has been undergoing promotion in the area for some time which is beginning to produce results at present; b) Developing hedgerows of Vetiver grass on the vulnerable banks to trap sediment and resist scouring of the banks in the flood events- Vetiver with its deep and dense root system offers this function in a more effective ways, c) Live staking with bamboo along erodible banks- this holds merit for the area due to rapid growth, dense root system and flexibility of bamboo which provides both immediate and longer term protection of stream banks; d) Brush layering and brushwood check structures to stabilize steep banks and, over time, create vegetated terraces to stabilize the stream banks. These interventions reduce erosion, stabilize stream banks and increase streambed roughness and all of these lower downstream flood velocities.

ii. **Establishment/Restoration of Riparian Vegetation Corridors:** Given patchy riparian vegetation prevailing along the streams in the area, restoring/establishing riparian vegetation along the streams would be one of the most effective NbS for channel health. This can be promoted by: i) Establishing 20–30 m wide riparian green belt on both sides of streams, where feasible; ii) Planting of native flood plain species, such as simal, bamboo, kans grass and amriso on the bank slope to restore stream bank resilience to flooding and erosion; and c) Protection of floodplain depressions as natural water storage areas, which would help reduce the peak discharge and enhance infiltration.

iii. **Reconnecting Streams with the Floodplain:** Channelization and construction of flood control embankments have disconnected many streams from their floodplains, which is known to have increased downstream flood peaks while reduce groundwater recharge by not allowing the floodwater to spread over the floodplain. Reconnecting the streams to its floodplain would be therefore essential to enhance groundwater recharge, reduce channel incision, and improve ecological function of the area. This can be promoted through one or more of following NbS measures: a) Identifying and opening controlled spill zones along the stream that would allow monsoon overflow to spread across safely in the floodplain; b) Rehabilitation of natural oxbow depressions to act as seasonal retention basins; and c) Removing unnecessary bunds and obstructions, such as restricted drainage path, in the flood plain that cause seasonal inundation and silt deposition on the agricultural lands.

iv. **Sediment Control Using Nature-Based Check-Dams and Grade-Control Structures:** Kandara and Kateni and their tributaries carry huge amount of sediment in the monsoon eroded from Chure slope. Establishing small vegetated structures in these channels to slow down the flow velocity and trap sediment load would hold merit to stabilize the stream channel in longer run. Some of the NbS options to this end, which would hold merit in the area are: i) Developing brushwood check-dams, bamboo barriers, and vegetative sills in small tributaries; ii) Developing staggered, low-height permeable check-dams on the smaller amd medium steams to reduce the flow velocity without blocking the flow to cause inundation in the upstream areas; and iii) Establishment of gully plugs and vegetated drop structures in actively eroding gullies feeding the main streams. These NbS measures would reduce sediment transport to downstream wetlands, restore deeper pools in the stream channels and prevent clogging of canal intake locations.

v. **Ecological Improvement of Traditional Irrigation Canals:** Traditional canals existing in the two sub-watersheds are silted, over-expanded or hydrologically disconnected from surrounding areas. Some of the NbS measures that can enhance their ecological functions and performance and therefore worth promoting in the area are: a) Grass sodding of canal embankments using vetiver, kans, or amriso to prevent erosion; b) Development of sediment traps at canal intakes made from vegetative barriers rather than concrete; c) Lining only the most leakage-prone segments while keeping most of the canal alignment earthen to support infiltration and local recharge; d) Allowing drainage and return flow from irrigated area to enter into the canal- this provision is known to enhance economical and efficient use of water in the irrigated command area; and e) Promoting eco-friendly desilting, utilizing manual and vegetative methods to reduce disturbances in the canal banks and beds. These measures offer more balanced approach to improve efficiency and water utilization in the canal command area.

vi. **Groundwater Recharge through Steam-Canal System:** Leveraging streams and canal systems and their segments to function as recharge structures would be useful to address the problem of groundwater decline that is beginning to appear in the southern Terai plains in the study area. Following NbS options would be useful to this end: a) Developing recharge trenches parallel to streams and canal to capture the overflow and seepage and allow it infiltrate into the groundwater system; b) Developing permeable check-dams at suitable locations in the streams and canals that would create ponding for slow infiltration; c) Development of off-stream infiltration basin, linked to the streams through temporary canals, to promote infiltration of water into groundwater system. These measures enhance dry-season base flow and support recharge of shallow aquifers used by farmers by developing large number of shallow tube-wells in the area.

6.4 Groundwater Management

Groundwater forms the most reliable year-round water source for both domestic and irrigation uses in the study area. However, rapid expansion of shallow and deep tube-wells, reduced infiltration in the Chure and Bhabar zones, and increasing dry-season water stress signal emerging risks of depletion. To secure long-term groundwater availability, NbS offer cost-effective, ecologically sound approaches that strengthen natural recharge, regulate extraction and integrate community-based stewardship. The following NbS measures for groundwater management are tailored to the hydrogeological context of the Siwalik foothills, the Bhabar zone and southern Terai's shallow and deep aquifer systems.

i. **Establishing Community Based Groundwater Monitoring System:** Effective groundwater management begins with understanding seasonal groundwater trends. However, both the sub-watersheds currently lack systematic groundwater monitoring mechanism. Well observation data of existing observation wells, established by erstwhile Groundwater Resources Development Board (GWRDB) of GoN is not shared in the public domain. Given signs of the groundwater depletion appearing in the study area and in other parts of Terai, establishing institutional mechanism for groundwater monitoring and data sharing at community level holds merit. In this context following NbS options would hold relevance to the study area: a) Installation of community-managed observation wells at representative locations-- upland recharge areas, mid-slope Bhabar zone and Terai plain where extensive groundwater use prevails, to track seasonal water table fluctuations; b) Establishing a simple groundwater monitoring protocol for local governments and Water Users Groups (WUGs), involving measurement and reporting of depth-to-groundwater table on monthly basis using manual dip meters; and c) Establishing spring discharge measurement points in the upland and Bhabar zones to provide indicative value on recharge and likely groundwater trends in the downstream areas. These measures put in place would be foundational to promoting managed aquifer recharge (MAR) in the study area.

ii. **Managed Aquifer Recharge (MAR):** Given the highly permeable Bhabar deposits and alluvial formation of Terai, the study area is naturally suited for MAR interventions to enhance infiltration of rainwater and surface runoff during monsoon peaks. This would produce dual benefits of groundwater recharge and downstream flood control. Some of the context specific MAR measures that would hold merit for the area are: a) Construction and/or rehabilitation of ponds/lakes, depressions and oxbow remnants as seasonal recharge hubs; b) Establishment of brushwood, bamboo, or stone-pitched perforated check-dams in gullies feeding Kandara and Kateni streams to slow runoff and allow infiltration into the subsurface formation- this will produce dual benefits of gully stabilization and groundwater recharge, c) Promotion of controlled stream spreading areas for monsoon flows to disperse across floodplains to allow increasing infiltration and reducing erosive peaks of flood flow, d) Development of trenches, staggered pits, vegetated contour lines and mulching to enhance infiltration in the Chure slopes that feed springs and shallow groundwater; and e) Ensuring clay free sub-surface formation in the agricultural lands which constitute largest land use in the study area-- with the use of tractor drawn rotavator for tillage operation in saturated condition for cultivation of rice, formation of plough pan is liable in heavy soils, creating impervious barrier to impede downward drainage of water. These measures put together would improve monsoon recharge, sustain dry-season groundwater levels and lower pressure on tube-wells.

iii. **Integration of Recharge Pits and On-Farm Infiltration Structures:** Establishment and utilization of recharge pits are known for their prudent value in promoting groundwater recharge in alluvial formation. Recharge pits are particularly beneficial where shallow aquifer levels are dropping and where seasonal flood can be harvested for recharge. Following recharge pit based NbS options would hold merit for the study area: a) On-farm recharge pits, 1–3 m deep and filled with gravel/sand layering, to capture field runoff and monsoon rainwater; ii) Development of percolation trenches along the farm boundaries to redirect storm water into the recharge pits; iii) Establishment of recharge shafts in high-infiltration zones, near ponds, canals and farm roads; and iv) Integration of infiltration pits with canal systems, capturing canal seepage and overflow into infiltration galleries.

iv. **Pumping Regulation and Demand Side Management:** Although establishing and enforcing formal regulation is often difficult given open access nature of the groundwater, soft governance combined with ecological incentives can effective in controlling extractive use of groundwater. Some of the measures of regulated use of groundwater that hold promise for the study area are: a) Establishing and institutionalizing groundwater withdrawal guidelines at municipality level informed by monitoring data and seasonal recharge patterns; b) Promoting conjunctive use of surface water and groundwater in the irrigated command area-- shifting part of irrigation demand to surface water in the monsoon season, c) Encouraging cultivation of low water demanding crops (millet, mustard, pulses, fodder species) in winter and spring season when dependence on groundwater for irrigation is high; d) Introducing rotational pumping schedule involving the WUGs to prevent over-extraction at critical dry periods when simultaneous groundwater pumping can produce drawdown; and e) Discouraging construction of new shallow and deep tube-wells in the zones already showing falling water tables and where potential recharge is limited.

7. Concluding Remarks

Kandara and Kateni sub-watersheds are at a critical hydro-ecological juncture. The study confirms that while the region is endowed with a rich diversity of water sources, the functional integrity of these systems is rapidly eroding. The intricate hydrological connectivity between the upstream Chure recharge zones and the downstream Terai aquifers is being disrupted by a combination of climatic stress and anthropogenic mismanagement.

The narrative of water in this landscape is one of transition and tension: a transition from surface water dependency to groundwater exploitation and a tension between economic resource extraction (fisheries, riverbed mining) and ecological preservation. The decline of traditional *Tharu* community management systems in the plains of Terai and small landholders and ethnic minority groups in the hills has left a governance void that modern municipal frameworks have yet to effectively fill. Without urgent and integrated intervention, the region faces a future of heightened flood risks, drying of springs and groundwater insecurity.

Key findings that draw attention and action of water sector and environmental agencies are as under:

i. **Disruption of Hydrological Connectivity of the Area:** This is likely to magnify given natural "sponge" function of the landscape is failing. Road construction in the Chure hills is cutting off spring lines while the embankment of ponds for commercial fisheries is sealing recharge zones in the plains.

ii. **"Flashiness" of Surface Water Systems:** This has increased over time and likely to intensify in future as the rivers and streams in the area are becoming increasingly erratic. Heavy sedimentation has raised riverbeds, causing streams like Kandara and Kateni to frequently shift their course and break their banks. Flood damage is no longer just a recurrent natural disaster but a systemic failure compounded by constrictive infrastructure (bridges/roads) and loss of riparian buffers.

iii. **Commercialization vs. Conservation of Wetlands:** Of the 55 inventoried ponds, many are being aggressively altered for high-yield aquaculture. The use of heavy machinery to deepen ponds and raise dykes destroys the natural littoral zones essential for biodiversity and blocks the seasonal overland flows that sustain the ponds. Short-term revenue generation for municipalities is being prioritized over the long-term ecosystem service of groundwater recharge.

iv. **The Groundwater Pivot and Governance Void:** There is a massive, unregulated shift toward groundwater irrigation. While currently reliable, this reliance is unmonitored. Simultaneously, the traditional *Badghar/Bhalmansa* system that managed water equitably are weakening. The "tragedy of the commons" looms for groundwater resources, as individual pumping replaces collective management without any regulatory oversight.

v. **Institutional Paralysis:** Conservation efforts are stalled by jurisdictional ambiguity. Local governments and Forest Offices often work in silos or in opposition regarding the ownership of water bodies located in forest fringes. Effective watershed management requires a harmonized legal framework or co-management agreements that bridge administrative boundaries.

The sustainability of the Kandara and Kateni sub-watersheds depends on recognizing that water management is livelihood and ecosystem management and securing the future. The current piecemeal approach, treating a pond as a fish farm, a river as a gravel mine, and a spring as an isolated tap, is ecologically unsustainable. The path forward lies in adopting Nature-based Solutions (NbS) as the central planning paradigm. This would be instrumental in:

i. **Restoring the Connectivity:** Physically reconnecting rivers to floodplains and ponds to aquifers.

ii. **Reviving Stewardship:** Empowering local communities to co-manage resources, blending their traditional ecological knowledge with modern conservation science.

iii. **Integrated Governance:** Establishing a trans-municipal watershed authority to coordinate upstream protection with downstream risk reduction

By pivoting to these resilient, ecosystem-centered strategies, stakeholders can ensure that the Kandara and Kateni landscapes continue to support both their rich biodiversity and livelihoods of the communities that depend on them.