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RESEARCH ARTICLE

Hydrogeological assessment of groundwater resources in Khutti Khola Watershed, Siraha District, Eastern Nepal

Goma Khadka[1], Sumitra Dhungana[1], Manjari Acharya[1], Ram Bahadur Sah[1] and *Kabi Raj Paudyal[1]

[1]Central Department of Geology, Tribhuvan University, Kathmandu, Nepal

**Corresponding author: paudyalkabi1976@gmail.com*

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ABSTRACT

The Khutti Khola watershed, located in eastern Nepal, is a region that has been experiencing increasing water scarcity over the past few decades. These regions face water scarcity due to rapid and poorly planned urbanization, fragile geology, overexploitation of existing water resources and ineffective water governance systems. The present study focuses on examining the availability, distribution, and management of groundwater resources in Khutti Khola watershed. It provides insights into the geological features, hydrogeological inventories, water table dynamics of Khutti Khola watershed and a Nature-based Solution (NbS) for groundwater recharge at water scarce areas of Bhabar zone. Hydrogeological assessment was carried out in Terai, Bhabar as well as Chure region within Khutti Khola watershed and the local people from the communities were interviewed for the identification of water scarce areas. The main scarcity was found in places like *Ranaha, Dadatol* and *Simaltoki* in the Bhabar zone. Recommendations for the development of artificial ponds were proposed in those areas as a Nature-based Solution (NbS) and a feasibility study was carried out for identifying the appropriate location for the pond. As such ponds made at the surface of the recharge zone will work as extra pockets to store surface runoff and recharge the area, construction of artificial recharge pond is recommended as sustainable solutions to mitigate water scarcity in the Khutti Khola watershed and similar regions across Nepal, ultimately improving livelihoods and resilience of local communities.

Keywords: ***Khutti Khola watershed, Groundwater resources, Bhabar zone, Nature-based Solution (NbS), Artificial recharge pond***

INTRODUCTION

The people living in Khutti Khola watershed depend on groundwater for both drinking and irrigation purposes. But these regions are at risk of water shortages because of rapid and poorly planned urban growth, along with fragile geology, and ineffective water management systems. In addition to these, the region relies heavily on monsoon rains, which are highly seasonal and unpredictable. Most of the annual rainfall occurs during the monsoon season, leading to a surplus of water for a few months and scarcity during the dry months.

The Bhabhar zone of the Khutti Khola watershed faces significant water unavailability primarily due to its highly porous and thick gravelly substrate. The northern part of the watershed consists of the Siwalik range separated by the Main Frontal Thrust. This zone is also fragile and porous in nature. There is huge accumulation of loose sediments at the base of the Siwalik, called the Bhabar zone, which acts as the recharge zone for the rest of the Terai regions southward (Neupane and Paudyal, 2021; Neupane et al., 2023; Dahal and Paudyal, 2022). Though the region facilitates groundwater recharge, access to water remains limited in the shallow aquifer because of the deeper water table (Pathak 2016; Luitel et al., 2020) leading to a lack of accessible water for agricultural, domestic, and ecological needs. Groundwater in the Bhabar Zone is accessible during the monsoon season, but the water table recedes significantly during the pre-monsoon period, causing shallow wells to run dry. Lahan municipality and Dhangadimai Municipality of Khutti Khola watershed have already been drilling sub-surface to extract water from deep aquifers and lifting surface water from rivers to meet immediate water supply demands. This may solve the problem of water scarcity in the short-term; however, these solutions are costly, unsustainable in the long term, and vulnerable to climate variability such as damage of the pipeline of the system by flood/landslide.

To address these complex issues, the concept of Nature-based Solutions (NbS) is gaining attention. NbS involves using natural systems or processes to manage water resources, rather than relying solely on conventional infrastructure (UN Water, 2018; UN Environment-DHI, UN Environment and IUCN, 2018). In the context of the Bhabar zone, the identified NbS is the construction of artificial recharge ponds. This approach aims to enhance groundwater storage by allowing rainwater and surface runoff to infiltrate into the aquifer naturally, replenishing groundwater levels. Based on hydrogeological assessment conducted and series of discussion and knowledge exchange among stakeholders, constructing sites for artificial recharge ponds was identified and prioritized as the most appropriate intervention to recharge groundwater in Bhabar zone in the study area.

Study area

The Khutti Khola watershed area is in the Siraha district of Madhesh province, Nepal, spanning between approximately 26° 42' 20" to 26° 55' 0" north latitude and 86° 23' 30" to 86° 31' 10" east longitude. It encompasses parts of Lahan municipality and Dhangadhimai municipality. The watershed exhibits a dendritic and parallel drainage pattern, characterized by major tributaries such as Khutti Khola, Sarre Khola, Ambule Khola, Maini Khola, Maina Khola, Raini Khola, Raydhar Khola, Dalame Khola, Mahajani Khola, and Madhyan Khola. The topography varies from gentle to steep in the northern section, gradually transitioning to flat plains in the southern section.

Methodology

This study encompassed a comprehensive approach involving literature review, field investigations, data compilation, and analysis. Topographic maps (Risku, Dhangadhimai, Lahan and Kadarbona of sheet no: 2686 02 B, 2686 02 D, 2686 06 B and 2686 07 A which covers overall Khutti Khola watershed were used for the preparation of location map, geological map, hydrogeological inventory and water level maps in GIS. Field investigation was carried out to collect detailed information on geology and hydrogeological condition of the area. Geological map from the Department of Mines and Geology (DMG 1984), Government of Nepal has been used as reference for geological survey in the field. Hydrogeological inventory of wells and springs within the Khutti Khola watershed was conducted during fieldwork. Information on water scarcity areas was gathered through social surveys in local communities (Figure 3). A feasibility study was undertaken to identify suitable locations for constructing artificial recharge ponds. The design and location of ponds within the watershed were determined considering three important factors: runoff collection, drainage channels and safe disposal of excess water. The national guideline provided by Department of Local Infrastructure Development and Agriculture Roads (DoLIDAR) was considered for recommending pond types (DoLIDAR, 2013).

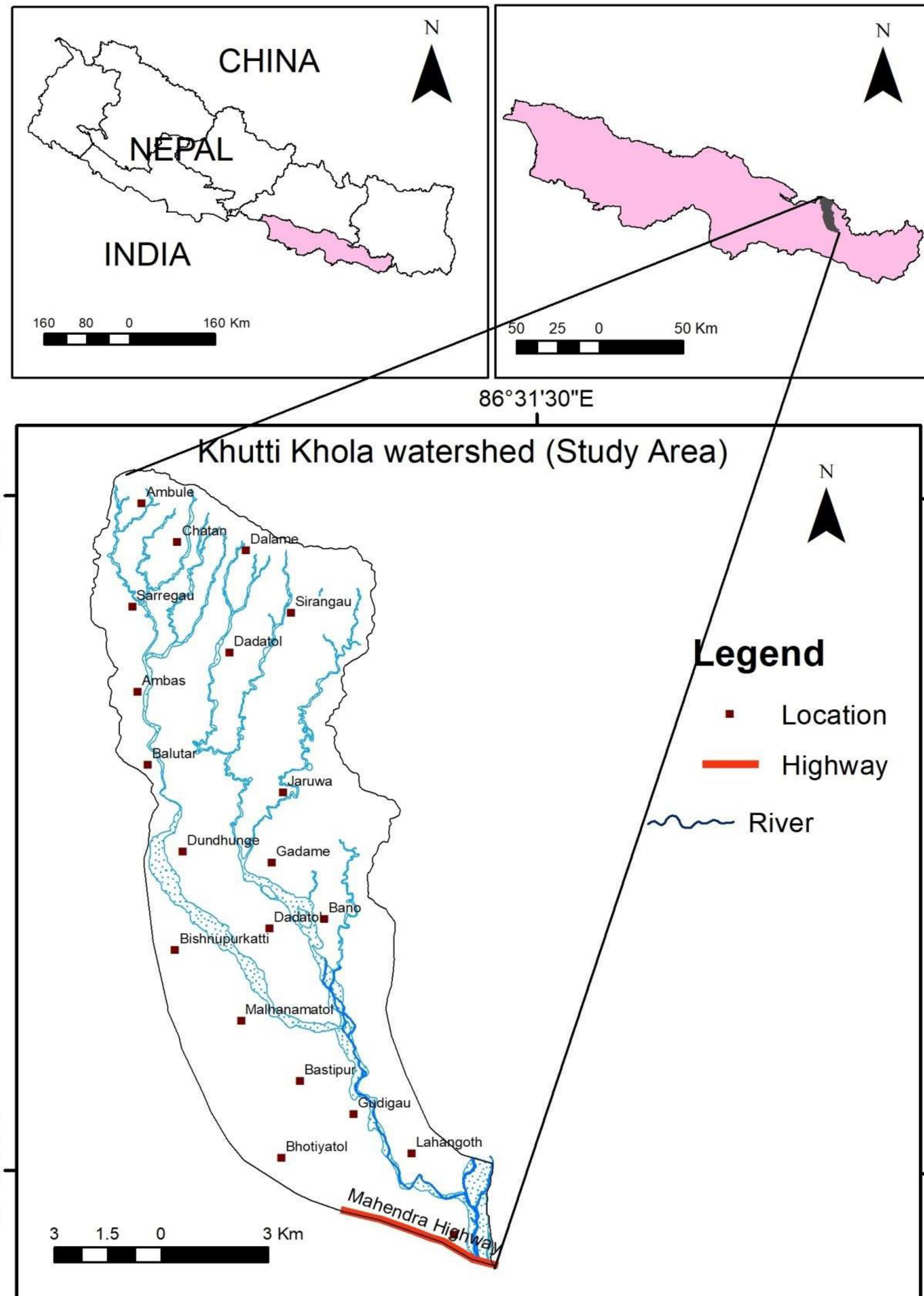

Fig. 1: Location map of the study area

Results

Geology

A detailed geological map of the area at a scale of 1:25000 has been prepared from the data collected during the field study (Figure 2). The study area is geologically diverse, comprising two major geological units: the Sub-Himalaya and the Terai Plain. It encompasses the Terai plain to the south and the Siwalik Group/ Sub-Himalaya/Chure Region succession to the north, separated by the Main Frontal Thrust (MFT). The Siwalik Group includes Lower Siwalik, Middle Siwalik (further divided into Middle Siwalik 1 and Middle Siwalik 2), and Upper Siwalik. The Terai plain is also divided into the Bhabar Zone and the Middle Terai in the studied section. Boundaries between these geological units have been delineated based on evidence such as lithological characteristics, structural features, and geomorphological indicators.

The Upper Siwalik comprises a thick-bedded conglomerate with loose sandstone and mudstone. Poorly sorted, clast-supported, less compacted conglomerate in the lower part of the Upper Siwalik is followed by poorly sorted, matrix-supported conglomerate bed towards stratigraphic up-section. Middle Siwalik comprises inter bedding of pale yellow to dark grey, fine- to coarse grained, thin-to thick-bedded sandstone, and pale yellow to ash grey, thinly bedded mudstone. The Middle Siwalik is further subdivided into the Middle Siwalik 1 and the Middle Siwalik 2. The Middle Siwalik 1 consists of greenish grey to light yellow mudstone and pale yellow, fine- to medium-grained, salt and pepper appearance sandstone in the lower portion. The proportion of sandstone increases in the upper portion. The Middle Siwalik 2 unit consists of thick-bedded, medium-to coarse-grained, salt and pepper appearance sandstone with thin-bedded pebbly sandstone at the lower portion. The proportion of pebbly sandstone increases toward the upper portion. The Lower Siwalik consists of purple, light yellow, ash to greenish grey variegated mudstone, black shale, and ash grey, fine-medium-grained sandstone. The spheroidal weathering in the mudstone bed is common.

The Terai plain is subdivided into the Bhabar zone and the Middle Terai. The Terai plain consists of boulders, gravel, silt, and clay of Quaternary alluvium deposits. The Bhabar zone lies immediately south of the Main Frontal Thrust at the foothill of the Chure. The Bhabar zone comprises rounded to sub-rounded gravel, cobble, pebble and coarse-grained sand. The Middle Terai mainly comprised of coarse to fine-grained sand, silt, and clay. The Recent Riverbed Deposits cover some parts of the study area along the river course which includes boulders, cobbles, pebbles, sand, silt, and clay.

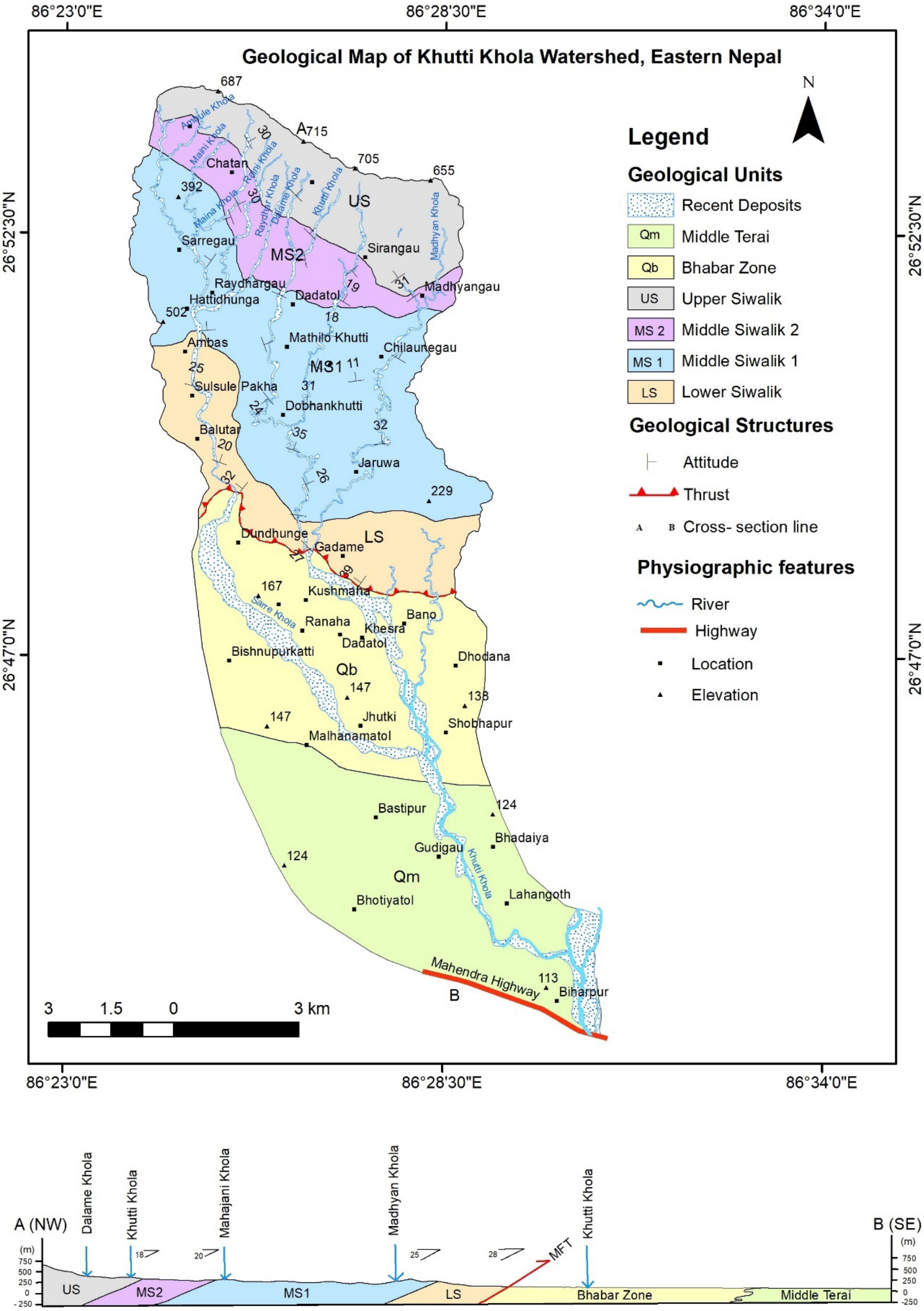

Fig. 2: Geological map and cross-section (through line A-B) of the Khutti Khola watershed area.

Hydrogeology

Hydrogeological study was carried out in the Siwalik region, Bhabar zone and the Middle Terai for finding availability and distribution of groundwater resources in the watershed. The information about shallow tube wells, deep tube wells, and springs was collected from the field and is listed in Tables 1 and 2. Some photographs from the field during hydrogeological inventory are shown in Figure 4 whereas Figure 5 depicts the hydrogeological inventory map.

Well inventory

The local people constructed dug wells, hand pump and deep tube well for the drinking and household purposes in the study area. Well inventory of the Khutti Khola watershed was done to find the availability of the water, static water level, drilling depth and depth of aquifer zone. The deep tube well data was collected from the Groundwater Irrigation Development Division (GWIDD) office, Lahan. The deep tube well data includes GPS coordinates, lithology data, elevation, and static water level. In the Siwalik zone, dug wells are constructed mostly on the bank of the river which is of shallow depth. The number of dug wells and hand pumps are large, but the number of deep tube wells is less in the Bhabar zone. Both hand pumps and deep tube wells can be seen in the Middle Terai. The quality of tube well water is predominantly satisfactory across most of the surveyed areas. This conclusion is based on the data collected by interviewing local people, which shows that most regions have access to water that meets acceptable quality standards for drinking which is within the concentration limits of Nepal Drinking Water Quality Standards (NDQS, 2005) and has no side effects and is used for all purposes including agriculture.

Table 1: Inventory of shallow and deep tubewell within Khutti Khola watershed.

Well Type	Well. No.	X	Y	Place	Elevation (m)	Total depth (m)	Static water level (m bgl)
Hand pump	T1	449520.3	2954360.1	Raghunathpur	110	13.7	1.5
Hand pump	T2	444607.4	2960456.4	Malanhma	126	18.2	14.8
Hand pump	T3	445954.6	2958684.8	Bastipur	118	45.7	9.1
Hand pump	T4	448320.5	2958766.2	Bhadaiya	132	8.5	5.2
Hand pump	T8	446043.8	2958266.3	Ragunathpur	120	15.2	4.8
Hand pump	T12	447619.9	2962838.1	Dhodana	131	30.5	15.0
Hand pump	T15	448194.8	2961472.2	Birnagar	127	9.1	1.2
Hand pump	T16	448380.0	2958537.4	Bhadaiya	125	8.5	5.2
Hand pump	T17	447743.4	2961495.3	Shobapur	119	6.1	1.2
Hand pump	T18	445461.7	2963307.0	Dadatol	136	16.8	15.2
Hand pump	T19	448448.3	2957832.3	Asanha	108	38.7	30.5
Hand pump	T23	449151.7	2957956.2	Magartol, Bhadaiya	120	34.1	30.5
Hand pump	T25	448781.7	2959000.4	Bishnupur	110	29.0	25.0
Hand pump	T26	447899.9	2957852.9	Gudigau	120	24.4	22.0
Dug well	W1	446510.9	2962109.1	Khesra (Magartol)	157	14.4	12.6
Dug well	W2	445867.2	2963362.8	Dadatol	161	19.8	14.4

Dug well	W3	445402.4	2963393.7	Dadatol	168	11.1	7.2
Dug well	W4	445360.3	2963694.3	Dadatol	163	30.6	26.1
Dug well	W5	445591.7	2963228.9	Motidadatol	166	36.0	28.0
Dug well	W6	442599.2	2966487.5	Bhotetar	201	5.4	3.6
Dug well	W8	442768.8	2965669.4	Dundunge	203	5.5	4.5
Dug well	W10	443184.0	2964244.8	Bishnupurkatti	186	12.6	9.0
Dug well	W11	441780.2	2969815.7	Ambas	256	18.0	8.1
Dug well	W12	442027.9	2969066.3	Ambas	251	8.0	5.7
Dug well	W13	441841.9	2971080.2	Hattidhunga, Dhangadhimai	277	3.6	2.7
Dug well	W16	444545.0	2969692.0	Mahajani	265	3.0	2.3
Dug well	W17	446485.4	2969761.5	Chilaunegau	264	2.8	2.5
Dug well	W18	444238.2	2963358.2	Ranaha	172	12.6	11.7
Dug well	W19	444521.3	2963119.0	Ranaha	165	52.5	37.5
Dug well	W20	444851.4	2962942.3	Ranaha	164	14.0	12.0
Dug well	W22	444360.6	2963790.1	Simaltoki	170	15.3	9.9
Dug well	W23	443029.0	2962366.9	Bishnupur-12	170	27.0	15.3
Dug well	W24	443458.7	2962001.6	Bishnupurkatti	169	12.6	9.6
Dug well	W26	443270.0	2961064.1	Raitol	163	13.0	11.7
Dug well	W27	443191.0	2960737.9	Raitol	160	14.5	7.2
Dug well	W28	444263.7	2960213.2	Premtol	155	15.0	13.5
Dug well	W31	446643.1	2970171.2	Chilaunegau	243	2.8	2.5
Dug well	W32	444402.7	2965229.8	Ahale	164	5.4	2.7
Dug well	W36	444084.2	2963668.8	Simaltoki	145	10.4	9.6
Dug well	W37	443861.6	2963805.8	Simaltoki	147	15.3	9.9
Dug well	W39	443131.4	2961694.6	Bishnupurkatti	136	15.0	14.0
Deep tubewell	DTW-1	445291.8	445291.8	Khapanitol	132	78.0	13.0
Deep tubewell	DTW-2	444461.3	444461.3	Malhnmatol, Govindapur	130	157.0	15.0
Deep tubewell	DTW-3	445995.1	445995.1	Govindapur	150	104.0	25.0
Deep tubewell	DTW-4	448211.5	448211.5	Bhadaiya-1	136	112.0	14.0
Deep tubewell	DTW-5	448330.6	448330.6	Bhadaiya	135	101.0	15.0
Deep tubewell	DTW-6	446652.2	446652.2	Bastipur	131	126.0	14.0
Deep tubewell	DTW-7	446109.1	446109.1	Bastipur-12	130	129.0	15.0
Deep tubewell	DTW-8	442510.4	442510.4	Bishnupur-11	146	95.0	12.0

Spring inventory

The maximum resident of the Siwalik (Chure) depends on the spring's water for drinking and other household purposes. Spring inventory was carried out in Siwalik to check the availability of the water. The study was done in Magh/Falgun months, a dry season in Nepal. Almost all the observed springs are perennial. The various types of spring observed are springs from riverbed, springs from colluvium, contact springs and seepage.

Springs from riverbed

The riverbed spring is found near the *Chilaunegau*. The riverbed containing sand, gravel and boulders provide the origin of spring water. The upper part of the stream was found dry. The *Chilaunegau* lies in the Middle Siwalik near to the Madhyan Khola. The whole of *Chilaunegau* depends on this riverbed aquifer for drinking and other domestic purposes.

Springs from colluvium

The maximum springs observed in the study area are colluvium originated springs. The colluvium spring is observed in *Ryadhargau, Sarregau, Bhibare and Bhalutar*. *Ryadhargau* and *Sarregau* lies in the upper part of Lower Middle Siwalik. *Bhalutar* and *Amiletar* lies in the Lower Siwalik.

Contact springs

The contact spring flows between mudstone and brown siltstone inter bedded within light grey, medium grained sandstone bed. It is observed near Lower Middle Siwalik near the *Mahajani* village. Another contact spring can be seen near the *Bhalutar* in the Lower Siwalik. It is observed between pale yellow, fine – grained sandstone and greenish mudstone bed.

Seepage springs

Seepage is seen in the contact of the fine-grained compacted sandstone and medium grained sandstone bed. It is observed on the left bank of the Khutti Khola about 1.5 km upstream from confluence of the Khutti Khola and the Madhyan Khola. It lies in the Lower Middle Siwalik.

Table 2: Spring inventory data within Khutti Khola watershed.

S.N.	X	Y	Type	Discharge	Location
A1	441516.2	2972135.0	Spring from riverbed	Perennial	Mainamaini Dobhan
A2	441953.2	2971910.2	Spring from colluvium	Perennial	Sarregau
A3	441644.6	2971807.9	Spring from riverbed	Perennial	Sarregau
A4	441713.3	2968580.7	Spring from colluvium	Perennial	Bihibare
A5	441973.6	2968756.1	Seepage	Seasonal	Sulsulepakha
A6	444391.2	2965339.7	Spring from colluvium	Perennial	Ahale
A7	447012.8	2970546.7	Spring from colluvium	Perennial	Madhyangaun
A8	441454.6	2971370.0	Spring from colluvium	Perennial	Raydhargau
A9	441947.2	2967754.9	Spring from colluvium	Seasonal	Bhalutar
A9	444649.1	2969654.4	Contact Spring	Perennial	Mahajani
A10	444601.5	2966720.0	Seepage	Seasonal	Khutti Khola
A11	442405.8	2967854.3	Contact spring	Perennial	Bhalutar

Fig. 3: Interviewing local people from the Khutti Khola watershed.

Fig. 4: Some photographs of wells and springs from the Khutti Khola watershed.

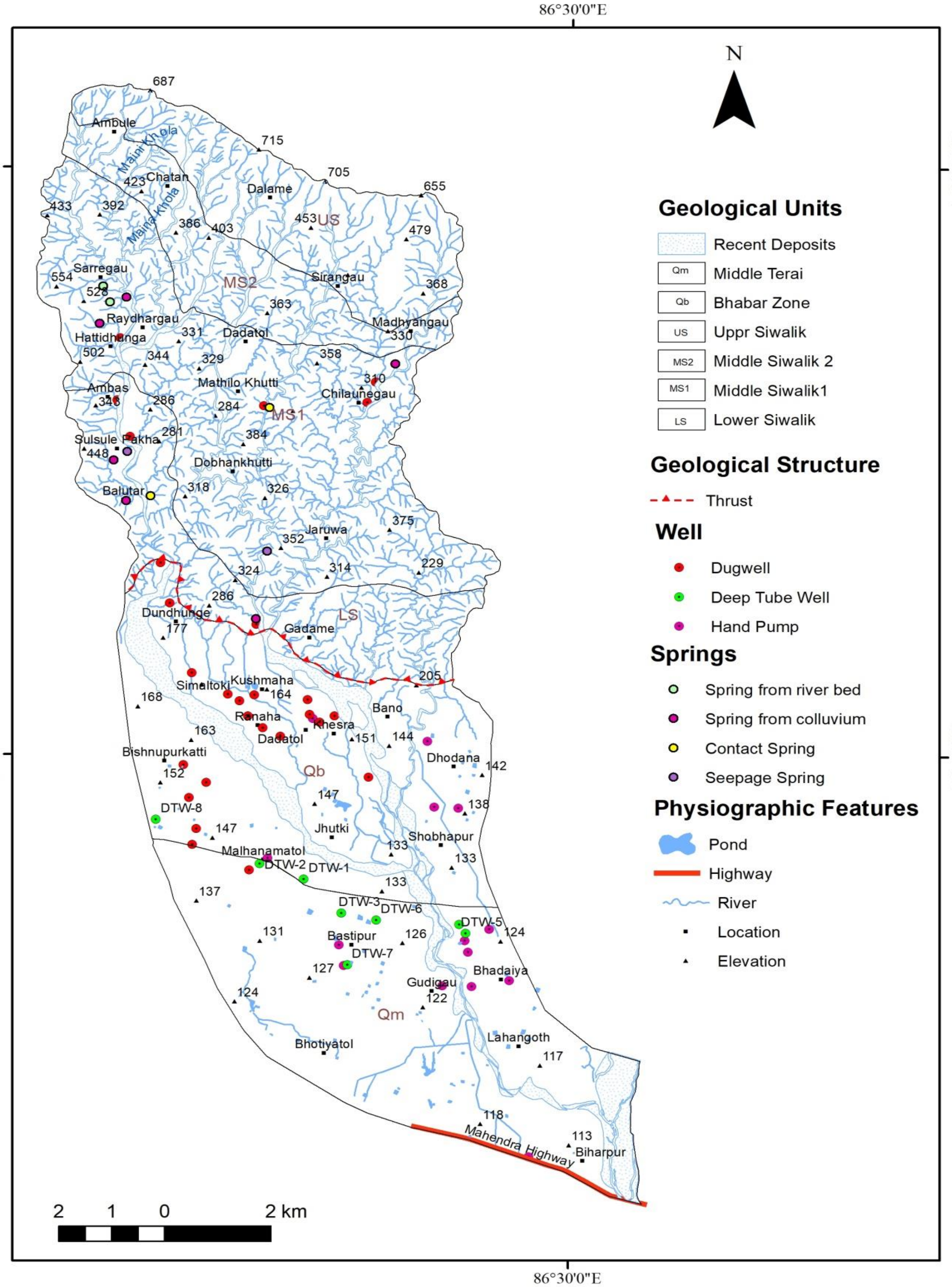

Fig. 5: Hydrogeological inventory map of the Khutti Khola watershed.

Depth of water level

Both drilling depth and static water level depth are measured during field visits. Based on the static water level of the shallow well, a water level map is prepared (Figure 6). The water level can be divided into 5 categories in the interval of 8 m bgl. The water level of the dug well in the villages named *Chilaunegau*, *Ryadhargau*, *Bhalutar* and *Mathillokhutti*, ranges between 1 m bgl and 8 m bgl. Wells are situated along the riverbanks in the Siwalik region, leading to a shallow static water level. In the Terai plain, the water level is at an intermediate level. Meanwhile, the water level in the Bhabar zone fluctuates depending on the location. In *Malhanmatol*, *Bishnupurkatti*, *Kushmaha*, *Gadame*, *Khesra* and *Dhodana villages*, the water level ranges from 8 m bgl to 16 m bgl. The water level of the *Ranaha* and *Dadatol* is from 24 m bgl to 32 m bgl. But in the *Shobapur* water level is at shallow depth. In the Middle Terai, the water table is found at a relatively shallow depth. The deep-water level lies around *Bhadaiya* and the *Gudigau* village.

Information about the subsurface of the area can be obtained from the litholog of the deep tube-well data available from the GWIDD office, Lahan (Figure 7). The deep tube-well drilled in the *Khapani* (DTW-1) was 78 m depth and static water level depth was 13 m. It consists of 28 m cobble and pebble, 11 m pebble and gravel, 34 m clay mixed with gravel and 5 m coarse - grained sand in the top layer. The litholog indicates that it lies in the Bhabar zone. The tube-well drilled at the *Govindapur* (DTW-3) was 104 m and *Bhadaiya* (DTW-4) was 112 m. DTW-3 consists of the thick layer of coarse-to medium - sand, a very thick layer of clay and thin layer of gravel. DTW-4 comprises of a very thick layer of clay with thick layer of sand and very thin layer of gravel. The contrast results are seen in the DTW-3 and DTW-4. In the DTW-3 and DTW-4 there is a thin layer of gravel and thick layer of sand, silt, and clay. Both tube-well litholog represent the sediments of the Middle Terai.

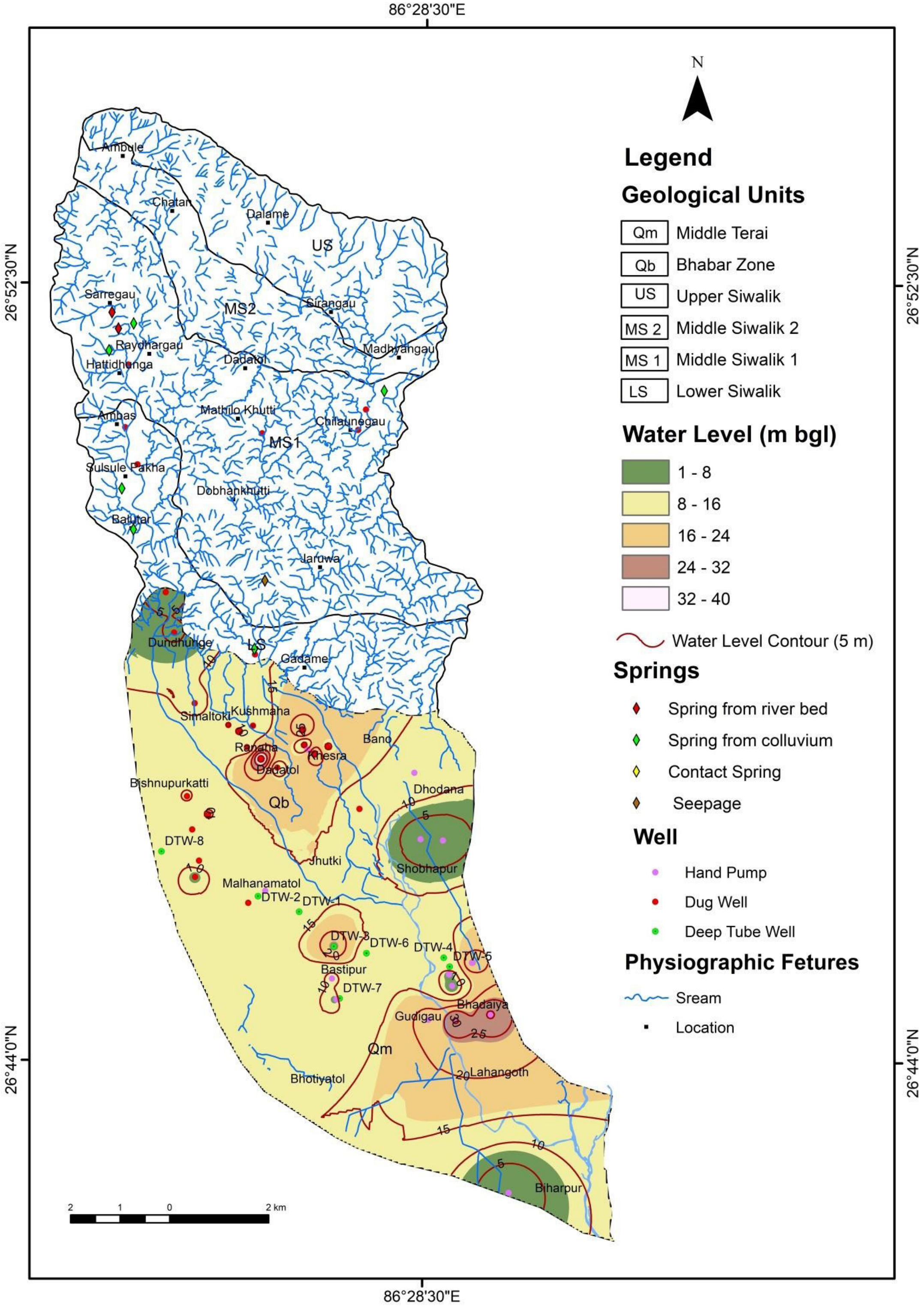

Fig. 6: Shallow water level map of the Khutti Khola watershed.

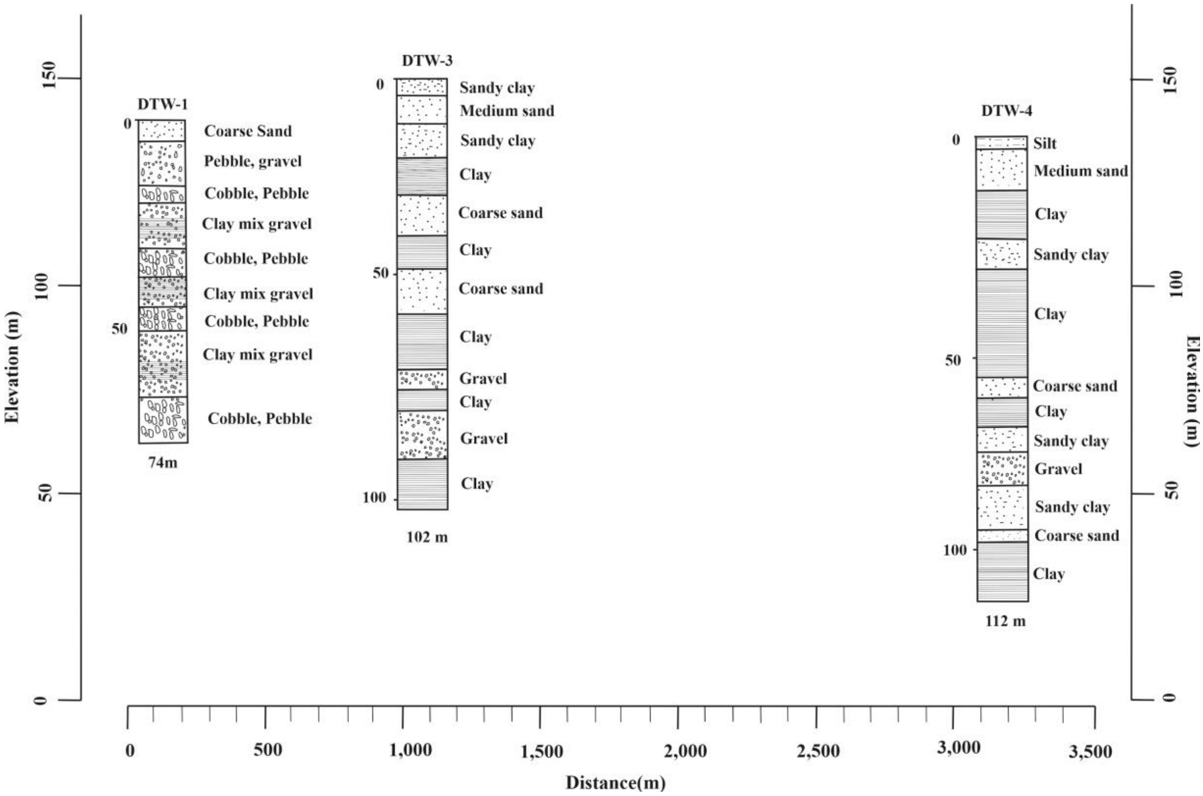

Fig. 7: Lithology of deep tube well from the study area.

Discussions and Conclusions

In the study area, Bhabar zone is still facing water scarcity problem. The Bhabar comprises of loose admixture of the cobble, pebble and coarse sand which are highly permeable and have less porosity. Many deep wells are constructed in the Bhabar to solve the water scarcity problem. But *Dadatol*, *Ranaha and Simaltoki* still have water scarcity problem in the dry season.

Addressing water scarcity is critical for ensuring the long-term sustainability and well-being of communities in the Khutti Khola watershed and similar regions. One of the most effective and sustainable Natural based Solution (NbS) methods to combat water scarcity is the implementation of artificial recharge ponds (Shrestha et al. 2021; Aryal et al., 2022). Additionally, use of water from the riverbed aquifers could be another alternative to harness the water in the region (Paudyal et al., 2023). However, in the present study, the possibilities of riverbed aquifers are not fully considered. A recharged pond is proposed at *Ranaha, Dadatol* and Simaltoki (Table 3) which is expected to solve the water scarcity problem of the communities from the *Ranaha, Dadatol* and *Simaltoki* tole. It lies in Bhabar zone which is a suitable place for recharging groundwater. The main purpose of ponds is to recharge groundwater and maintain water level in all seasons. The locations were chosen based on several criteria, communities demand including their ability to collect runoff, their status as public land, and their position in the bhabar zone, where there is no impermeable clay layer. This ensures that runoff and rainfall can easily infiltrate into the soil.

Table 3: GPS location of proposed recharge pond

S.N.	Northing	Easting	Spot Height	Place Name
1	444381	2963235	163	Ranaha
2	445145.5	2963357	165	Dadatol
3	443946.9	2963475	167	Simaltoki

Conclusions

The assessment of groundwater resources of the Khutti Khola watershed identified the availability of groundwater through well and spring inventories, revealing varying water levels across different zones. The Bhabhar zone struggles with water accessibility because of its highly porous substrate and deep-water table. Current engineering solutions like deep aquifer drilling and surface water lifting are costly and unsustainable in the long term. A promising sustainable solution is the implementation of Nature-based Solutions (NbS), specifically artificial recharge ponds, which enhance groundwater storage by allowing rainwater and surface runoff to infiltrate naturally. This helped in providing water for longer period and thus enhanced percolation rate boosting the replenishment of the underlying aquifers and hence increasing the well yield at shallow depth. The proposed recharged ponds at Ranaha, Dadatol, and Simaltoki are strategically located in the Bhabar zone, which provides favorable conditions for groundwater recharge. The ground conditions are ideal due to the absence of impermeable clay layers and characterized by its highly porous and thick gravelly substrate allowing for efficient infiltration of runoff and rainfall. Hence, artificial ponds are recommended in the Bhabar zone which will help the communities to combat water scarcity during dry seasons.

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Author contribu`tion

All the authors have made significant contributions to the development of this research article. First, Dr. Kabi Raj Paudyal and Ms. Sumitra Dhungana made the study concept and design. Ms. Goma Khadka accompanied the fieldwork with Sumitra Dhungana for two weeks and contributed a lot to field data collection. Dr. Kabi Raj Paudyal and Dr. Ram Bahadur Shah took verification traverses in the field with the team members. Ms. Manjari Acharya assisted in compiling and analyzing the field data. Ms. Goma Khadka also provided technical support to digitize the maps. The initial draft of the manuscript was written by Goma Khadka and all authors contributed to making the draft form of the manuscript into the final version. Finally, all the authors have contributed to making corrections as per the suggestion of reviewers.

Data availability

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflict of interest

The authors declare no competing interests.

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