Proceedings of 14th IOE Graduate Conference
Peer Reviewed
Year: 2023 Month: December Volume: 14
ISSN: 2350-8914 (Online), 2350-8906 (Print)

Assessment of Groundwater Availability in Western Terai of Nepal: A Study in Kailali District

Prajwol Aryal [a], Vishnu Prasad Pandey [b], Bhesh Raj Thapa [c]

[a, b] *Department of Civil Engineering, Pulchowk Campus, Institute of Engineering, Tribhuvan University, Nepal*
[b] *Center for Water Resources Studies, Institute of Engineering, Tribhuvan University, Nepal*
[c] *Universal Engineering and Science College, Lalitpur, Pokhara University, Nepal*
[a] 078mswre006.prajwol@pcampus.edu.np, [b] vishnu.pandey@pcampus.edu.np, [c] bthapa.ioe@gmail.com

Abstract
This study delineates spatial distribution of thickness and estimates static groundwater storage potential of shallow and deep aquifers in the lower plain of Kailali district. The groundwater storage potential, which refers to the volume of groundwater that can be extracted theoretically if the aquifers were completely drained, has been estimated by multiplying the aquifer volume with storage coefficient. Geographic Information System (GIS) is used for calculating the spatial distribution of storage potential throughout the study area. Borehole lithologs at 29 locations were obtained, reclassified into six lithological units and further into four hydrogeological units such as Aquiclude, Aquitard, Aquifer-1 and Aquifer-2. Only the lower lands of Kailali having elevation less than 1,000 meter above mean sea level has been considered as study area. The storage coefficient or storativity value of the aquifers is taken from the published literature. The study results show that the thickness of shallow aquifer is found higher in central region (i.e. up to 60m) where as deep aquifer is found to be thick in the south eastern region (up to 128m). Static groundwater potential of shallow aquifer in the Kailali district is found to be higher than that of deep aquifer. Total static water storage potential of shallow Aquier-1 is estimated as 17,112 million cubic meters (Mm^3) where as in deep Aquifer is only 885 Mm^3. The shallow aquifer of the district is found to have higher storage potential in the central region whereas deep aquifer is found to have higher potential in south eastern region.

Keywords
Groundwater, Aquifer, Storage coefficient, Storage potential

1. Introduction

Water present beneath the Earth's surface in rocks and soil pores is Groundwater. About 30 percentage of World's freshwater is estimated to be Groundwater [1]. In the context of Nepal, groundwater serves as an attractive, reliable and easily accessible source of water with numerous benefits [2]. The shallow aquifers in Terai has been considered as good productive shallow zones with water quality suitable for irrigation as well as drinking purpose [3]. The Northern part of Indo-Gangetic plain, Terai of Nepal is elevated from 60m to 200m [4]. The Terai plain mostly dominated with young alluvial deposit, contains multiple layers of good aquifer layer at different depth, interconnected to some extent [1]. Besides having huge potential, the groundwater in Terai region of Nepal has just been extracting about 22 percentage of the total available dynamic groundwater recharge [3]. The Terai region, located in the foothills of Churia faces severe water scarcity due to limited access to surface water, where groundwater seems to be better alternative for domestic and agricultural purposes [5]. About 90 percentage of population rely on groundwater to fulfill their domestic demands in Terai region [6]. The water quality in Terai is considered to be good with most of the parameters falling in satisfactory range of World Health Organization (WHO) guidelines except arsenic being newly emerging problem in Terai's shallow aquifer [7]. Though Terai has abundance groundwater potential, the need of consumptive use has been felt due to continuous increase in population and increasing demands [8]. Using water resources sustainably requires water governance that uses a holistic and integrated approach to the management of water and related resources [9]. Being a part of larger Gangetic basin, Terai holds a good position with respect to renewable groundwater resource [10]. The Northern part of Terai along the foothills of Siwalik range is the Bhabar zone. Bhabar zone which consist of coarser colluvium and alluvial fan deposit where sediment size decreases gradually towards south [4] is considered as the main recharge zone for the aquifers in Terai[11].

Deforestation and rapid human encroachment in Bhabar zone pose a great threat to the groundwater resources in lower Terai zone [10]. Although groundwater and its management is rising issue, the field of groundwater studies in Nepal is severely lacking in adequate groundwater database and research activities [12]. Most of the study in the Western Terai has been concentrated towards analysis of arsenic containment, related hazards and mitigation measures only [13, 14]. Using water resources sustainably requires water governance that uses a holistic and integrated approach to the management of water and related resources [9]. Groundwater potential mapping of an area will serve the vital information and knowledge for better planning and development of irrigation facilities to the farmers [11]. Mostly the research in the Western Terai has been concentrated for accessing the water quality. Very few study related to groundwater storage potential has been done in the study area, which this research considers as gap and intent to fulfil.

2. Study Area and Methodology

The study area of this research is one of Nepal's 77 districts, Kailali District. It is located in Sudurpashchim Province in the Terai plain. The population of the district is 911,155(2021 census) and (775,709 in 2011 census). Dhangadhi is its capital with residence of about 22 % of total district's population. Kailali has a total area of 3,235 square kilometers (1,249 square miles). The district is located at (28034'00" N 80047'00"E). The district's elevation ranges from 135 m above mean sea level (masl) to 1,967 m with a tropical to subtropical climate. The district is broadly classified into four different geographic regions: Siwalik Hills, Bhabar zone, Middle Terai and Lower Terai. Out of district's entire land area, 24.9 % is agricultural land and almost 71 %, is forest [15]. About 150,000 ha of district's land is potential land for irrigation. The average annual rainfall is about 1,840 mm and average evapotranspiration is about 700 mm. The study area along with spatial distribution of sample boreholes is depicted in Figure 1.

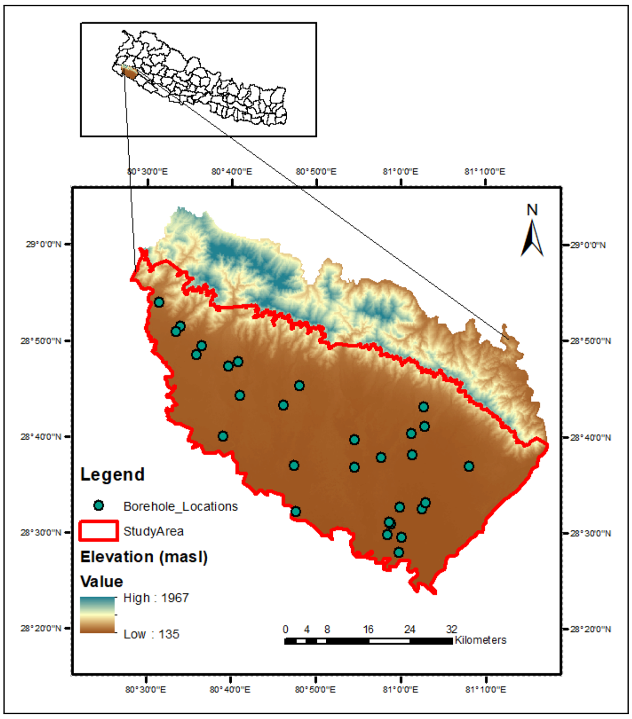

Figure 1: Study Area

The Siwalik region above 1000m elevation has been discarded for this particular study. As the Siwalik zone which have the elevation higher than 1000m from mean sea level consists of alternate beds of sandstone, mudstone and conglomerate, are associated with very low groundwater potential. The areal extent of our study area is depicted in Figure 1. The previous study conducted by [16] suggested about 1,927 km² out of total district's area has potential for groundwater. We have considered 2,324 km² area of Kailali for this study. The study area is further divided into 37,514 numbers of grids of size 250m x 250m for analysis in GIS.

2.1 Data Preparation

The main focus of this phase is on making data available and getting them ready for input. The first stage is to choose the study region, determine whether data are available, prepare GIS database. 29 lithological data all were obtained from the record of GWRDB, Dhangadhi, Kailali which were modified considering the resistivity logs available rather than completely relying on the driller's log. The locations of borehole are depicted in Figure 1. The data obtained with their sources is depicted in Table 1.

Table 1: Data and Sources

S.N.	Data	Sources
1	Lithological data	Groundwater Resource Development Board (GWRDB) Dhangadhi, published literature
2	Storage coefficient data	Ministry of Irrigation(MOI), GWRDB Bara, [17],[18]

2.2 Reclassification of lithologs and hydrogeological units

The obtained lithologs were reclassified mainly into 6 (six) categories. These categories were selected by extensive consultation with the hydrogeologist working in the field. The reclassification process was done with the help of resistivity logs available, based on the knowledge of subsurface geology and expert's suggestions. Electric Resistivity method measures the ability of electrical current to flow through the subsurface. Lithologs are reclassified based on their resistivity values in ohm-m on long normal curve taking basis from [19]. The range of resistivity for classification of lithologs are presented in the Table 2.

Table 2: Reclassification of Lithologs

SN	Apparent Resistivity (ohm-m)	Lithological type
1	less than 5	Sticky clay
2	5 to 15	Silty clay
3	15 to 25	Sandy clay
4	25 to 40	Clayey gravel
5	40 to 75	medium to coarse sand
6	more than 75	Gravel

Including few meters of Top soil layer, we have considered four different Hydrogeological units beneath the ground surface. The selection of these units is based on the expert's guidance and subsurface geology of the area. The first layer along with top soil is Aquiclude which is considered to have very low or zero water yield, beneath Aquiclude, Aquifer-1 is present which is considered to have sufficient water yield and found to be unconfined to semi-confined in nature. This layer has significant value of storage coefficient that can be called as specific yield as it lies in shallow depth. Aquitard is the next layer considered which is assumed to have low value of water yield but not nil. The last layer on further depth is considered as Aquifer-2 which is considered to have significant amount of water yield and found to be unconfined to semi-confined in nature. This unit have certain value of storativity though very less than that of specific yield. The various hydrogeological units that have been categorized on the basis of lithological units is presented in the Table 3.

Table 3: Reclassification of Hydrogeological units

S.N.	Lithological type	Hydrogeological units
1	Top soil, Sticky clay	Aquiclude
2	Sandy clay, Silty clay	Aquitard
3	Clayey gravel, Medium to Coarse sand, Gravel	Aquifers

2.3 Storage coefficient

The storage coefficient or storativity is the volume of water released from storage with respect to the change in head (water level) and surface area of the aquifer. Storativity for shallow aquifer is the specific yield. Previous studies conducted suggested the value of specific yield to lie between 0.1 to 0.3, so due to unavailability of specific yield data in the area we have taken the value of specific yield 0.2 for this study. The study conducted by [20] in Northern and Southern bank aquifer of middle Ganga plain, India suggested the value of storage coefficient ranging from 6.36 x 10-3 to 1.26x10-4. During the study of tube well inventory of 22 district of Terai, it has suggested the storage coefficient value of 0.005 in the study area. Another district in Terai Bara, Birgunj Groundwater Resource Development Board(GWRDB) has also suggested value of storativity 0 .005. Storativity value of 0.005 has been taken for this specific study.

2.4 Mapping aquifer thickness and aquifer storage potential

Two aquifers, Aquifer-1 and Aquifer-2 has been identified beneath the subsurface of the study area. Reviewing previous studies and on consulting with experts working in the area the aquifer up to depth 50 m has been considered as shallow. The Aquifer-1 is considered to be shallow aquifer in this particular study. The Aquifer-2 at more depth is considered to be deep aquifer. Elevation raster of each hydrogeological units has been prepared in GIS. The unknown elevations of bottom of every grid of size 250mX250m has been calculated using kriging interpolation technique in GIS. For the calculation of aquifer's thickness, the elevation raster of bottom of a hydrogeological unit has been subtracted from the following elevation raster located at greater depth. The spatial variation of Aquifer's thickness has been depicted in the Figure 2 which shows that south eastern part and central part of Kailali consist of thick aquifer layers.

For the calculation of aquifer volume raster calculator has been used. Thickness raster of each aquifer layer has been multiplied with the area raster prepared dividing the whole considered area (2,324km^2) into 250mX250m grid size. The area is divided into 37,514 numbers of grids. Only the volume of Aquifer-1 and Aquifer-2 has been calculated for this particular study. The water storage potential of Aquiclude has not been assessed since this unit is considered to have zero storativity value. Despite having low storativity value the water storage potential of Aquitard unit also has not been assessed. Water storage potential of the aquifers has been calculated by multiplying the aquifer volume and their respective storage coefficient value in each grid cell and finally total water storage volume is calculated by adding all the individual volumes in every grid.

3. Results and Discussion

This particular study aims to map the aquifer thickness and groundwater storage potential of the Kailali District with the help of secondary data available. The aquifer thickness and water storage potential with their spatial distribution has been assessed in the study.

3.1 Spatial distribution of thickness of hydrogeological units

Including top soil, Aquiclude layer is considered as first hydrogeological unit. This layer's thickness ranges from 7.9m to 13.4m. Western and Central region of Kailali has been found to have thin layer of Aquiclude layer whereas eastern region consists of relatively thick layered Aquiclude. Underneath the Aquiclude comes the first aquifer layer called as Aquifer-1 layer. This layer ranges from 20.6m to 60.1m thick. Most of the central region and regions in and around Dhangadhi are found to have thick shallow aquifer whereas western and eastern region of the study area are found to have relatively thin shallow aquifer. On moving further deep comes the Aquitard layer whose thickness ranges from 7.3m to 13.7m. Thick Aquitard layer are found in central region followed by western region. Eastern region has been found to have thin Aquitard layer. The forth layer on further depth is Aquifer-2 layer whose thickness ranges from 44.1m to 118.3m. South eastern, central and area in and around the Dhangadhi sub-metropolitan are found to have good deep aquifer potential whereas other areas have relatively thin Aquifer-2 layer. The spatial variation of thickness of different hydrogeological units throughout the study area is depicted in the Figure 2, Figure 3, Figure 4 and Figure 5.

3.2 Spatial distribution of aquifer volume

The volume of shallow aquifer i.e. Aquifer-1 layer is found to be higher in the central region of Kailali district. The western and most of the eastern region are found to have relatively lower volume of Aquifer-1. Minimum of 1.28 Mm^3 to maximum of 3.75Mm^3 of Aquifer-1 is found in per unit of grid having grid size 250mX250m. South eastern region along with central region of the district are found to have good deep aquifer potential as these regions consists of higher volume of Aquifer-2. The remaining regions, north eastern and western region has relatively lower volume of Aquifer-2. The volume per unit grid of the Aquifer-2 ranges from 2.75Mm^3 to 8.02Mm^3. The spatial distribution of aquifer volume in both Aquifer-1 and Aquifer-2 is depicted in Figure 6 and Figure 7.

3.3 Spatial distribution of groundwater storage potential

The water storage potential of Aquifer-1 is found to be ranging from 0.25Mm^3 to 0.75Mm^3 per unit of grid cell. Similarly, the water storage potential in Aquifer-2 is found to be ranging from 0.01Mm^3 to 0.04Mm^3 per unit of grid cell. The total volume of water storage in Both Aquifers throughout the study

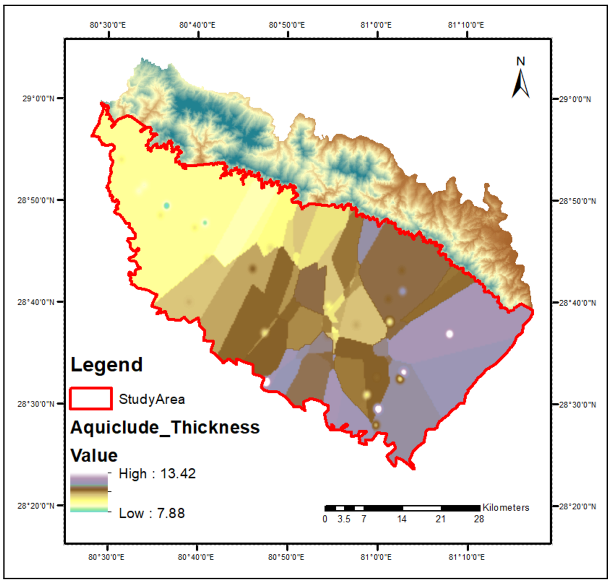

Figure 2: Thickness of Aquiclude

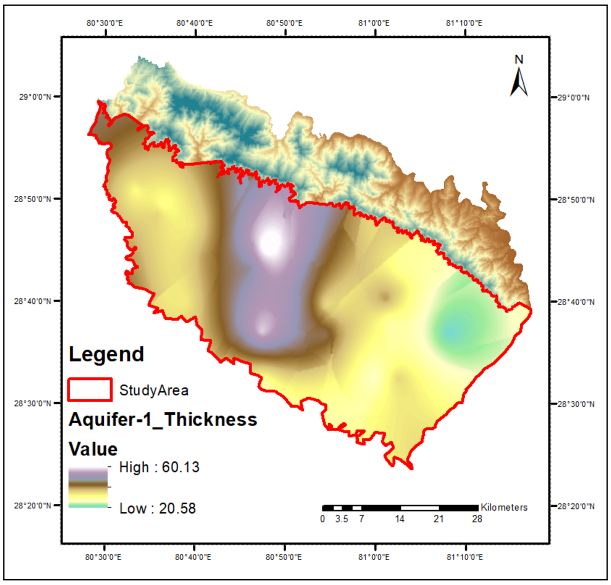

Figure 3: Thickness of Aquifer-1

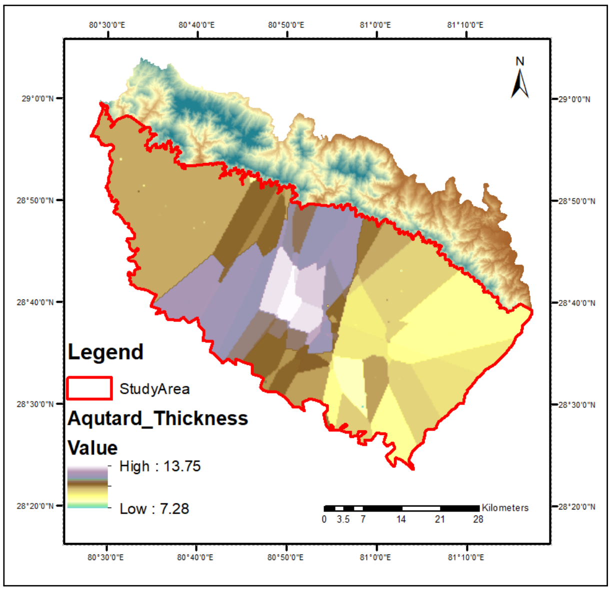

Figure 4: Thickness of Aquitard

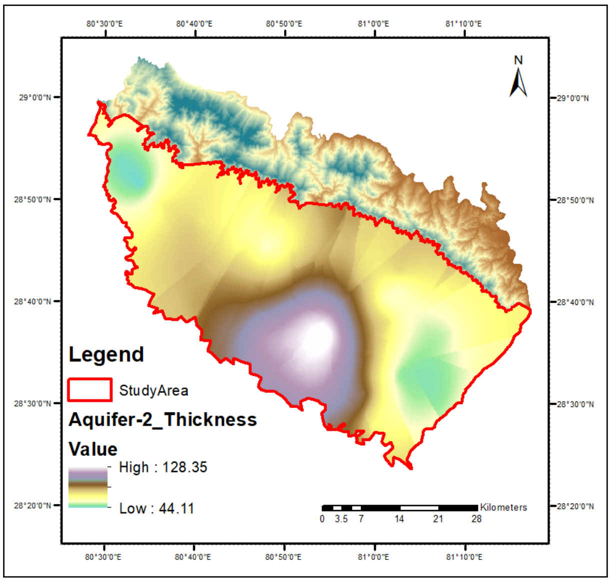

Figure 5: Thickness of Aquifer-2

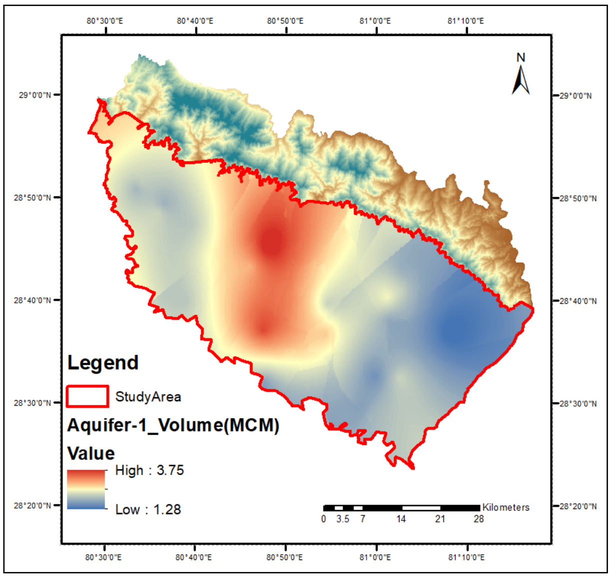

Figure 6: Volume of Aquifer-1

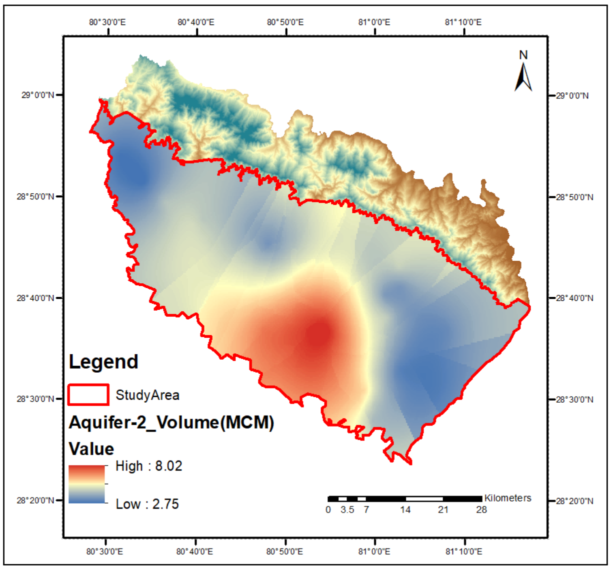

Figure 7: Volume of Aquifer-2

area is calculated by adding total unit volumes of water storage potential in each grid. Aquifer-1 is found to have a total of 17112 Mm³ of static water storage potential whereas Aquifer-2 is found to have a total of 885 Mm³ of static water storage potential. The static water storage potential in shallow aquifers is found to be much higher than the average annual renewable groundwater resources (864Mm³) in Kailali as presented in Irrigation Master Plan 2019. The results also align with the results of previous studies which stated that only eastern part has good prospects for deep tube wells [16] The spatial distribution of GW water storage potential is depicted in Figure 8 and Figure 9.

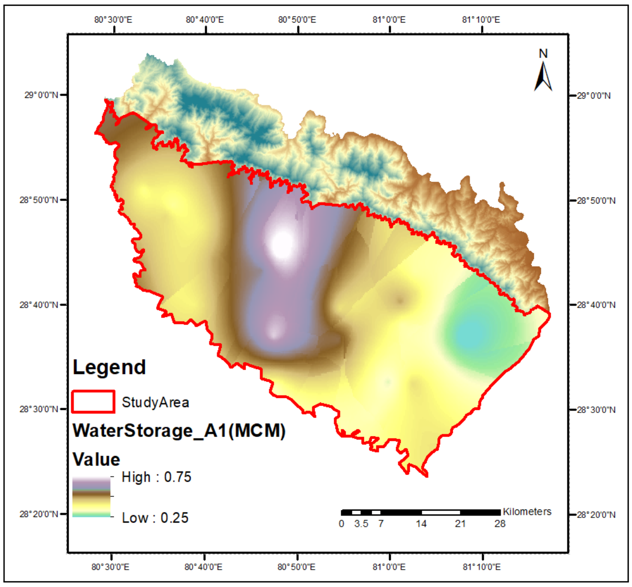

Figure 8: GW Storage potential in Aquifer-1

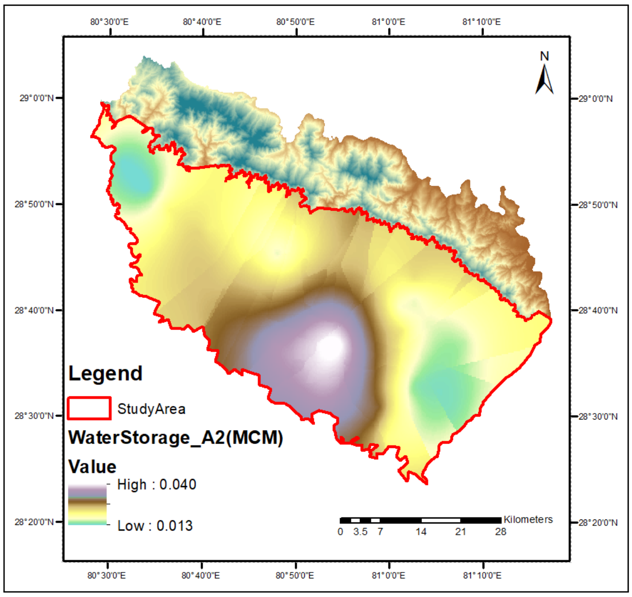

Figure 9: GW Storage potential in Aquifer-2

4. Conclusion

The study evaluated the water storage potential in both shallow and deep aquifers in the Terai region of Western Nepal. Water storage potential has been assessed using secondary lithological data of 29 boreholes available. The thickness of shallow aquifer is found to be lower in comparative of deep aquifer. As suggested by GWRDB, depth less than 60m has been found to be shallow aquifer in the study area. The static groundwater potential of shallow aquifer in the Kailali district is higher than that of deep aquifer. Total estimated groundwater storage potential of shallow Aquier-1 is 17112 Mm³ and that in Aquifer-2 is 885 Mm³. There is a wide spatial variation in storage potential in both aquifers. In shallow, it varies from 0.25 Mm³ to 0.75 Mm³/62,500m². In contrast, the maximum storage in major parts of deep aquifer is less than 0.04 Mm³/62,500m² only. Shallow aquifer has mostly been extracted for the fulfillment of domestic needs including drinking water whereas deep tube wells are found to be extracted for irrigational use. Therefore, if the natural/artificial recharge to the shallow aquifer could be maintained satisfactory than groundwater resource development in the area has huge potential. The results of this study indicates huge potential of shallow aquifer therefore under the present condition, expanding groundwater irrigation (including surface irrigation schemes as conjunctive use) appears to be better strategy since only about 46% of total cultivable land has access to surface irrigation facilities and are still scare to fulfil the irrigation water demand during dry season in Kailali district of Nepal. Digging of shallow tube wells could be prioritize for the fulfilment of most of the water demands in the study area. Through involvement of Local levels along with users group, the study area could be made water secure through conjunctive use of water and only shallow aquifers seems to be sufficient limiting the excavation of deep tube wells in most of the areas.

Only few borehole lithological data have been interpreted for the generation of the results. Instead of using the results of own pumping tests, the storage coefficient values were derived from the literature and research done on similar terrain in other areas of the vast Gangetic plain. Conducting pumping test in study area is not the scope of this study. Since none of the boreholes in the area have been drilled all the way to bed rock level, the deepest depth of the obtained bore hole (i.e. 220m) is taken into consideration as the deepest point for interpolation, lacking information of the bed rock's depth. So, here only the storage potential of deep aquifer up to 220m depth has been assessed. Further information of depth to bed rock's position may lead to calculation of actual water storage potential of whole deep aquifer. To determine a regional distribution of aquifer thickness, only 29 borehole lithologs were examined in this study, which might not represent a realistic scenario. Consequently, using additional lithological data could lead to more accurate results. Uniform spatial distribution of borehole locations also enhance the interpolation result which in overall improves the result. It is advised to collect storage coefficient information from primary pumping test results rather to depend on literatures. By taking into account the dynamics of groundwater flow and recharge characteristics, the estimates of groundwater storage potential could be enhanced. For it, a 3-D numerical model is required. As a result, it is advised that a numerical model be created to better understand the groundwater environment in the study area. This model also can be used to evaluate the effects of climate change on the availability and spatial distribution of groundwater resources.

Acknowledgments

The authors are thankful to Dr. Laxmi Prasad Devkota and Hydrogeologist Ram Datta Joshi for their valuable guidance, encouragement and support during this research work.

References

[1] Abhijit Mukherjee. *Overview of the groundwater of South Asia*. Springer, 2018.

[2] Shobha Kumari Yadav. Groundwater challenges, governance, and management in nepal. *Groundwater of South Asia*, pages 707–734, 2018.

[3] Surendra R Shrestha, Ganesh N Tripathi, and Dipendra Laudari. Groundwater resources of nepal: An overview. *Groundwater of South Asia*, pages 169–193, 2018.

[4] Toni Hagen. Report on the geological survey of nepal, vol. 1. *Denkschr. Schwez Naturf. Gesell., Bd.*, 86(1):1–185, 1969.

[5] Bhesh Raj Thapa, Surendra Raj Shrestha, Romulus Okoth Okwany, and Madhu Neupane. Shallow aquifer potential mapping in the foothills of churia in eastern gangetic plain of saptari district, nepal. *Applied Water Science*, 9:1–10, 2019.

[6] Adb/icimod. 2005.

[7] Jay Krishna Thakur, Rinku Kumari Thakur, AL Ramanathan, Manish Kumar, and Sudhir Kumar Singh. Arsenic contamination of groundwater in nepal—an overview. *Water*, 3(1):1–20, 2010.

[8] Debi Prasad Bhattarai and Narendra Man Shakya. Conjunctive use of water resources in sustainable development of agriculture in terai nepal. *Journal of the Institute of Engineering*, 15(2):210–217, 2019.

[9] Santosh Nepal, Nilhari Neupane, Devesh Belbase, Vishnu Prasad Pandey, and Aditi Mukherji. Achieving water security in nepal through unravelling the water-energy-agriculture nexus. *International Journal of Water Resources Development*, 37(1):67–93, 2021.

[10] Dibya Ratna Kansakar. Understanding groundwater for proper utilization and management in nepal. In *Proceedings of IWMI-ITP-NIH International Workshop on Creating Synergy between Groundwater Research and Management in South and Southeast Asia, Roorkee, India, February 8-9*, pages 95–104, 2005.

[11] Dinesh Pathak. Water availability and hydrogeological condition in the siwalik foothill of east nepal. *Nepal Journal of Science and Technology*, 17(1):31–38, 2016.

[12] Dhruba Raj Regmi, Saroj Karki, and Pawan Bhattarai. Application of gis based analytical hierarchy process (ahp) for groundwater potential mapping of nepal.

[13] Jasmine Diwakar, Scott G Johnston, Edward D Burton, and Suresh Das Shrestha. Arsenic mobilization in an alluvial aquifer of the terai region, nepal. *Journal of Hydrology: Regional Studies*, 4:59–79, 2015.

[14] Jaya K Gurung, Hiroaki Ishiga, and Mohan S Khadka. Geological and geochemical examination of arsenic contamination in groundwater in the holocene terai basin, nepal. *Environmental Geology*, 49:98–113, 2005.

[15] Nepal CBS. National sample census of agriculture nepal 2011/12. *National Report*, 2013.

[16] CK. Sharma. Shallow aquifers of nepal. 1995.

[17] Dipankar Saha and SN Dwivedi. Groundwater availability of northern and southern bank aquifers of the middle ganga plain, india. *Groundwater of South Asia*, pages 101–118, 2018.

[18] S Sahu, D Saha, and RR Shukla. Sone megafan: a non-himalayan megafan of craton origin, forming a potential groundwater reservoir in marginal parts of ganga basin, india. *Hydrogeology journal*, 26(8), 2018.

[19] ASM Woobaidullah, SM Shahnewaz, Md Munirul Islam, Md Kamrul Islam, and Md Zakir Hossain. Electrical resistivity survey in the investigation of hydrogeological condition of sylhet-sunamganj haor area, bangladesh. *Journal of Nepal Geological Society*, 58:21–28, 2019.

[20] Dipankar Saha and S. N. Dwivedi. *Groundwater Availability of Northern and Southern Bank Aquifers of the Middle Ganga Plain, India*. Springer Singapore, 2018.