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ARTICLE

Groundwater Recharge Potential Mapping in Far Western Middle Mountain of Nepal: A GIS-based Approach

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ABSTRACT

The larger population in the middle mountain region of Nepal is dependent on spring for domestic water use. Availability and flow regularity of springs rely on groundwater recharge (GWR) potential which is attributed to various natural and human factors. The present study is an attempt to explore the GWR potential using GIS and Remote sensing (RS) method in two watersheds of the far western middle mountains of Nepal. Spatial analysis is carried out using a weighted overlay analysis of six factors namely, slope, lithology, lineament, drainage density, rainfall, and land cover/ land use. The result shows that only 16 percent of the total watershed area is under a very high recharge potential zone while 31 percent area falls under very low recharge potential. It is found that the distribution of existing spring sources is random concerning GWR potential. Water stress in Rel Gad watershed is evident which accentuates the proper management of recharge areas. The study concludes that the GIS RS tool is useful in identifying recharge potential zones. It aids to better planning for increasing recharge potential. Proper management of recharge potential area and spring water sources direct the future water availability to fulfill the increasing water need of the communities.

1. Introduction

The role of water in human life and livelihood is well known and it's availability and accessibility impose constraints on water use [7]. The global demand for water has been increasing at a rate of about 1% per year as a function of population growth, economic development, and changing consumption patterns with the majority of the growing demand occurring in countries with developing economies. In 2010, twenty-seven percent of the global population lived in potential severely water-scarce areas which increased to an estimated 45 % (water-scarcity at least one month per year) in 2018 and estimated to increase to 60 percent by 2050 [48]. Similarly, it is estimated that 30 percent of all freshwater on earth exists as groundwater [43]. The demand for groundwater resources is increasing with the depletion of available primary surface water supplies. According to a study, groundwater use in the Asia region could increase by 30%

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by 2050 with severe groundwater stress in the Northern Plain of China and Northwest India[1]. Of the total global population, 31% depend solely on groundwater resources to satisfy their basic daily water needs [42]. It provides drinking water to at least 50% of the global population and accounts for 43% of all of the water used for irrigation [8]. The role of groundwater discharge is also vital for maintaining water levels in rivers originating from the mountains [45]. With the projected water scarcity and reduced renewable surface and groundwater resources, water availability and quality would be one of the major issues for societies, and rural areas are expected to experience major impacts on water availability and supply [15]. World Economic Forum reported that the highest level of societal impact over the next 10 years will be from water crises [47].

Open access to spatial data and availability of mapping and spatial analysis tools like Geographic Information System (GIS) and Image Processing/Remote Sensing (RS) has made a breakthrough in the field of groundwater recharge potential mapping and analysis [9,37]. GIS and RS based groundwater recharge potential mapping aids to field sample selection and site-specific exploration using geological, hydro-geological, and geophysical methods [13,26]. Integration of in situ methods like long term observation and measurement, flow analysis and modeling, and hydro/geostatistical analysis with GIS and RS tools in characterizing groundwater aquifers and modeling groundwater recharge is enduring research interest [6,22,25,49].

Groundwater exploration was first initiated in Nepal in 1967. Survey and mapping of groundwater recharge potential have been a field of interest for resource development and exploration in Nepal since the 1990s [33,37]. The renewable groundwater potential of Nepal is estimated to be 12 km^3 and in the middle hills and mountain region annual groundwater reserve is estimated to be at least 1713 MCM whereas in total shallow and deep groundwater aquifers are estimated to be 8.8 BCM annually [10.44]. However, most of the groundwater exploration using traditional methods is concentrated in the Terai plain area of the country, and urgency systematic study and exploration and assessment of the groundwater resources in the hill and mountain region is realized [2.30].

The larger population in the middle mountain of Nepal is dependent on natural spring water sources. Of the total population residing in upstream mountain slope areas, 80% of the communities have no direct access to the river water source, and natural springs are the primary source of water for sustaining domestic and agricultural water needs [34]. Pertaining to the IPCC assessment, the number of recent studies had reported decreasing water level and drying up of springs in the middle mountains of Nepal. Major factors attributed to decreasing water level and drying up of springs are, increasing population, changing land cover-land uses, environmental degradation, and spatial and temporal variability in rainfall [21,39]. In this context, the present study is an attempt to explore the groundwater recharge potential based on natural and human factors using GIS and Remote sensing method in two watersheds of the far western middle mountain region of Nepal.

2. Concept

Groundwater is stored in the open spaces within rocks and unconsolidated sediments beneath the earth surface between the unsaturated and saturated zone. Groundwater doesn't always flow in the same way as the surface water. However, it always flows from the recharge area to the discharge area. Recharge involves the influx of groundwater to an aquifer, while discharge involves the outflow of groundwater from an aquifer [31]. It flows downward passing between porous soil, sand, gravel, or rock due to gravity and also flows sideways due to pressure generated by water-resistant non-porous rock and soil. The direction and speed of groundwater movement are determined by the various characteristics of aquifers and confining layers of subsurface rocks. Groundwater movement through steep land slopes results in hillside flow to land surface in the form of natural springs or flow horizontally towards streams, rivers, or ocean [46]. Spring is an outflow of groundwater in a discharge zone at or below the intersected location between water table (with filled aquifer) and the geological structure/topography [24].

Geological structure dictates the occurrence and flow of spring, and topography drives the direction of groundwater flow whereas rainfall would influence the timing and amount of recharge and the volume and variability of discharge [41]. However, human activities also can influence the volume of water that discharges besides, size

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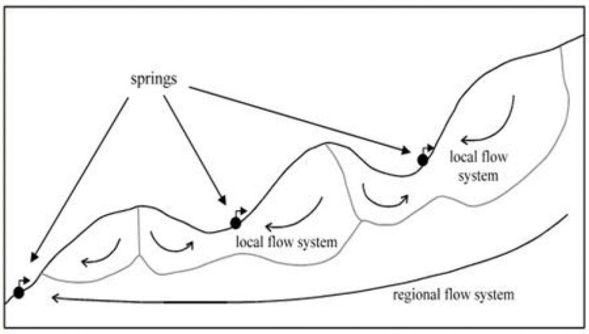
of the caverns within the rocks, the water pressure in the aquifer, the size of the spring basin, and the amount of rainfall [43]. Availability and flow regularity of spring water rely on groundwater storage and recharge potential of groundwater (Figure 1). Groundwater recharge potential, on the other hand, is attributed to many factors like rainfall, lithology, lineaments, slope, drainage density, and land cover/ land use, etc.



Effect of topography on groundwater flow patterns and location of source areas for discharge springs.

Source: Kreye et. al., 1996.

Figure1: Groundwater flow system

3. Materials and Method

The study has adopted an integrated approach and includes both desk work and fieldwork. Primary and secondary data sources are used for the proposed study.

3.1 Study Area

The two watersheds, one located in the southern slope and the other located in the northern slope of the middle mountain region of Far western Province of Nepal, is selected as the study area (Figure 2).

3.1.1 Dhung Gad Watershed

Dhung Gad watershed lies in the southern slope of the Baitadi district and covers 92 km^2 area. The altitude of the watershed ranges from 712 to 2807 m above the mean sea level. The settlement distribution is random and is located up to 2350m but most of the settlements are confined to the lower slopes and narrow river valleys (Figure 2). The Dhung Gad river originates from the north-western part and flows to the south-eastern part of the watershed. It is known as Dhung Gad in the southern part and confluences into the West Seti river. The average annual rainfall of the area is 1600 mm. The topography is rugged and 46 percent area is above 40-degree slope. More than 18 percent of the watershed area is barren and rocky which lies in the north-western part. Forest is the dominant land cover/use covering 56 percent of the total area. Agriculture covers around 29 percent of the total watershed area and settlements comprise 3 percent area coverage. The total population of the watershed area is 11, 116 and the total household is 1790 with an average household size of 6. The population density of the area is 120 persons per Km^2. The lower southern part of the study area is inhabited by different castes groups such as Brahman, Chhetri, and Dalit [4]. The primary occupation of the people living in this watershed is agriculture followed by foreign labor.

3.1.2 Rel Gad Watershed

Rel Gad watershed lies in the northern slope of the Doti district and covers 41 km2 area. The altitude of the watershed ranges from 723 to 2467 m above mean sea level. The settlement distribution is random and is located up to 1900m but most of the settlements are confined to the southern lower slopes and narrow river valleys. The Rel Gad river originates from the southern part and flows to the north-western part of the watershed. It is known as Golmagad in the southern part and confluences into the West Seti river. The average annual rainfall of the area is 1800 mm. As compared to Dhung Gad watershed, the topography is relatively moderately slope and around 9 percent of the total area is above 40-degree slope and 51 percent area is in-between 20 to 30-degree slope. However, more than 11 percent of the watershed area is barren and rocky which lies in the north-western part. Forest is the dominant land cover/use covering 66 percent of the total area. Agriculture covers around 21 percent of the total watershed area and settlements comprise only 1 percent area coverage. The total population of the watershed area is 5077 and the total household is 972 with an average household of 5.2. The population density of the area is 123 persons per Km^2. The lower north-eastern part of the study area is inhabited by different castes groups such as Brahman, Chhetri, and Dalit [4]. The primary occupation of the people living in this watershed is agriculture followed by foreign labor.

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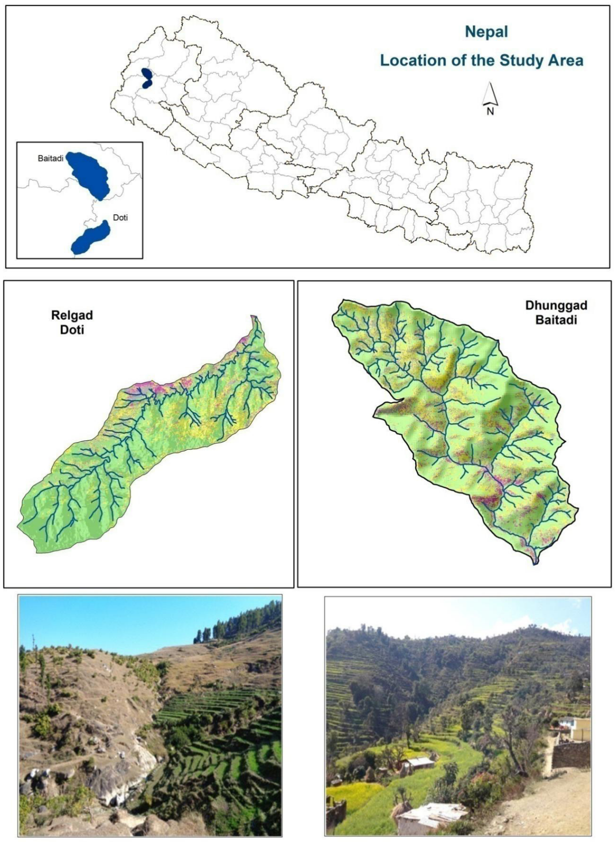

Figure 2: Study Area

3.2 Data and Method

Primary data was collected using questionnaires for household surveys, field observation, and key informant interviews. Primary spatial data i.e. spring locations were collected using GPS and inventory form. Secondary spatial data layers included lithology, soil, geomorphology, land cover/ land use, River network, elevation and rainfall which are collected from relevant authorities either in digital, or hardcopy sources while other spatial data layers (slope, drainage density, lineament density, watershed boundary) were derived using these data layers.

GIS and Remote sensing tools are applied to groundwater potential zone identification and exploratory analysis. Spatial analysis is carried out using weighted overlay analysis in GIS. Weight and factor rate assigned to each factor and factor classes are based on the review of several previous studies in the similar and different geographic settings [9,11,13,28,35,38,40]. The total assigned weight per factor class is calculated by multiplying weight and factor rate. This study is carried without incorporating the recharge and groundwater head data (pumping test of a well) and the location of spring sources is taken as a proxy to groundwater recharge aquifer. The six factors namely, drainage density, land cover/ land use, lineament density, lithology, slope gradient, and rainfall have been used in inferring the groundwater recharge potential area. The factors, weight per factor class, and factor rate are illustrated in Table 1.

Table 1. Groundwater Recharge Potential Factor Weight Assignment

SN	Factor	Class	Weight	Factor Rate	Assigned weight	Factor class
1	Drainage Density	Very High	6.5	1.5	9.75	0 .0 - 0.0012
		High	5		7.5	0.0012 - 0.0025
		Moderate	3.5		5.25	0.0025 - 0.0037
		Low	2		3	0.0037 - 0.0050
		Very Low	0.5		0.75	0.0050 - 0.0062
2	Land cover/ land use	Very High	6.5	2.5	16.25	Water/Snow
		High	5		12.5	Agriculture
		Moderate	3.5		8.75	Barren/ Abandoned
		Low	2		5	Forest
		Very Low	1		2.5	Built-up
3	Lineament Density	Very High	10	2	20	0.000152 - 0.000219
		High	8		16	0.000108 - 0.000152
		Moderate	6.5		13	0.000066 - 0.000108
		Low	5		10	0.000025 - 0.000066
		Very Low	3		6	0 - 0.000025
4	Lithology	Very High	10	3	30	NA
		High	8		24	Calcacareous Slate & Sandstones
		Moderate	5		15	Dolomitic Limestones
		Low	2		6	Phyllite and Phyllitic Quartzites
		Very Low	1		3	Augn Gneisses
5	Slope Gradient	Very High	10	1.5	15	0 - 10
		High	8		12	10 - 20
		Moderate	6.5		9.75	20 - 35
		Low	5		7.5	35 - 50
		Very Low	2		3	>50
6	Rainfall	Very High	10	3	30	2000 mm/ annum
		High				
		Moderate	6.5		19.5	1800 mm/ annum
		Low	3		9	1600mm/ annum
		Very Low				

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Recharge potential areas are divided into five categories from very good to very poor based on a calculated value from weighted overlay. Existing spring water sources, spring source user households, and settlements were overlaid against all categories of recharge potential to explore the relationship between the distribution of spring sources and recharge potential zones and existing use of sources. The groundwater recharge potential area is calculated using equation 1. The total calculated value using equation 1 was grouped into five classes from rank 1 to 5. The overall ranking into five classes is based on Jenk's natural break of the output data value. Jenk's natural break method is suggested for comparative analysis [18].

$\boldsymbol{GWR_p} = \sum(DD_w *DD_r + LD_w* LD_r + SG_w *SG_r + LT_w *LT_r + LU_w* LU_r +RF_w*RF_r)$...........equation (1)

where; $\boldsymbol{GWR_p}$ = Groundwater recharge Potential

DD: Drainage density, LD: Lineament Density, SG: Slope gradient, LT: Lithology, LU: Land use and RF: Rainfall, w = weight and r = factor rate assigned to each class category of individual factor

4. Result and Discussion

4.1 Groundwater Recharge Potential Factors

The present study used six factors as primary influencing factors namely, lineament density, lithology, land cover/ land use, drainage density, slope gradient, and rainfall. Three major types of relationship between different factors and groundwater recharge potential are exemplified in various literature [9,13,14]. Some influencing factors have a direct relationship with recharge potentials such as lineament density whereas some have a variable relationship like geology/lithology and land cover/ land use. Drainage density and slope gradient have an inverse relationship with GWR potential. Higher the drainage density, greater the runoff and lower is the GWR potential while steeper the slope, faster the runoff and hence lower the GWR potential. Table 2 summarizes the percent share of all six factors to GWR potential in the study area. The GWR factor map and potential GWR per factor are presented in Figure 3a for Dhung Gad and Figure 3b for Rel Gad watershed.

Lithology (LT) is regarded as the primary factor for infiltration and groundwater aquifer development. In the Hills and Mountains Region of Nepal groundwater occurs in unconsolidated sedimentary deposits [30]. The study area consists of metamorphic (dominantly, phyllites, phyllitic quartzites, and gneisses), sedimentary-metamorphic (dominantly calcareous quartzites and dolomitic limestones) and sedimentary (dominantly calcareous slate, shale, and sandstones). Sandstone, limestone, and slate are considered as having higher GWR potential, whereas phyllite, granite/gneisses is considered as having low GWR Potential. In the study area, only 11% of the total area has high GWR potential and is found in Dhung Gad, and no high GWR potential area is found in Rel Gad watershed while more than 61% has low GWR potential.

The lineaments features like faults, joints, and fractures provide open spaces for water inflow and underground storage. Higher the lineament density (LD) more favorable is the condition for the GWR Potential [32]. Lineament density is regarded as a proxy factor as the detailed lineament analysis needs detailed field investigations. Lineaments for the current study are identified from the satellite in the study area and not many lineament features are present. Higher lineament density is found in the northern part of Dhung Gad whereas density is higher in the southern part of Rel Gad. Of the total area, 44% is high potential to GWR and 39% is moderately potential. A study carried out in the middle mountains of Nepal also shows the strong likelihood of spring occurrence in the area of dense lineaments [9]. The existence of permeable fracture zones in less permeable high-grade metamorphic rocks increases the groundwater storage and spring occurrence. GIS and RS based studies show that the role of landforms and lineaments for the occurrence of high yield groundwater availability in hard rock terrain is very important as compared to weathered rocks [35].

Land cover land use (LU) is another important factor influencing groundwater recharge. However, it has a variable relationship depending upon other physical and human factors such as surface slope and intensity of use. In general, the area near water and snow cover tends to have higher potential followed by agriculture use while the built-up and barren area has lower potential as infiltration is constrained and runoff is faster [28]. Forest has moderate recharge potentiality. Forest is the dominant land cover comprising 59 % of the total area followed by agriculture area with 22 %. Upstream is of both watersheds are covered by dense forest and agriculture is found in lower hill-slopes. Barren and abandoned land cover 16% of the total area. Water and the built-up cover are very low with 2% and 0.04% respectively. Of the total area, 22% is a high potential for GWR while 61% area is under low to very low GWR potential. The effect of different land use on GWR potential is highlighted in several studies [2,14,40]. Correspondingly, the transformation of one land use class to another has also a variable effect on GWR potential [16]. A study has reported 11 to 100 percent of the natural groundwater recharge loss due to the transformation of the forest into built-up loss and up to 19 fold increase in runoff [12].

Drainage density (DD) reflects the infiltration and permeability capacity of underlying soil and geology. In general, a lower drainage density is found to be associated with regions having highly permeable subsoil material, whereas a high value of drainage density is noted for the regions of weak or impermeable subsurface materials [29]. However, relative relief and slope steepness largely control the drainage density, and the contribution of rivers and streams flowing through high degree slope is considered less significant to groundwater recharge. Low drainage density is thus associated with higher GWR potential. In the study area, 44% of the area is under high GWR potential and 17% area is under low to very low GWR potential. Interestingly, high GWR potential area in consideration of drainage density is found towards the southern part of north-facing watershed i.e. Rel Gad and towards the northern part of the south-facing watershed i.e. Dhung Gad.

The slope gradient (SG) controls the runoff and infiltration capacity of water. Steeper the slope gradient lower is the GWR potential due to rapid runoff and less possibility of water holding capacity and infiltration. This means the likelihood of GWR potential in the downslope area. The slope gradient is variable in the study area. of the total area, 52% is under a moderate slope of 20 to 35 degrees whereas 19% area is above 35-degree slope which is less potential for GWR. Likewise, less than 10% area is under 10-degree slope and is concentrated also narrow river valleys which have high GWR potential. The high frequency of the springs on straight slopes indicates the seepage of groundwater flow on a larger quantity from the downslope below the concave slopes, which acts as an intake of rainwater for groundwater recharge [9]. Water tends to store at lower topography rather than the higher topography. The higher the elevation, the lesser is the groundwater potential and vice versa.

Rainfall (RF) is the major controlling factor of GWR potential. A higher amount of rainfall increases the possibility of higher groundwater recharge. However, slope gradient and shape, vegetation cover, and underlying lithology largely determines the water holding and quantity of infiltration in an area of rainfall. The average annual rainfall in the study area ranges from 1600 to 2000mm. and more than 85% of the rainfall occurs during the monsoon period of June to mid-October. The study area lies in three different climate zone namely, tropical, subtropical, and temperate zone where temperature differs and so is the rate of Evapotranspiration which again affects the groundwater infiltration and storage. GRW potential regarding rainfall is high in 13% area of the total study area but is confined to the southern slope of Rel Gad. Low GWR potential is found in the Dhung Gad watershed. The nature and gradient of the surface onto which the rain falls have a significant influence on the infiltration rate. A gentle gradient with high vegetation cover will allow increased infiltration in comparison to the barren land. Barren land has a low capacity to absorb water and causes rapid runoff [13].

Table 2. Percent share of factors to GWR potential

GWR Potential	LD	LU	LT	DD	SG	RF
Very High	0.05	0.04	11.2	11.3	6.5	
High	43.6	22	27.4	40.9	22.4	13.7
Moderate	38.8	16	30.9	19.9	52.4	29.5
Low	15.3	59	20.5	14.5	18.0	56.8
Very Low	2	2.8	10	13.2	0.06	

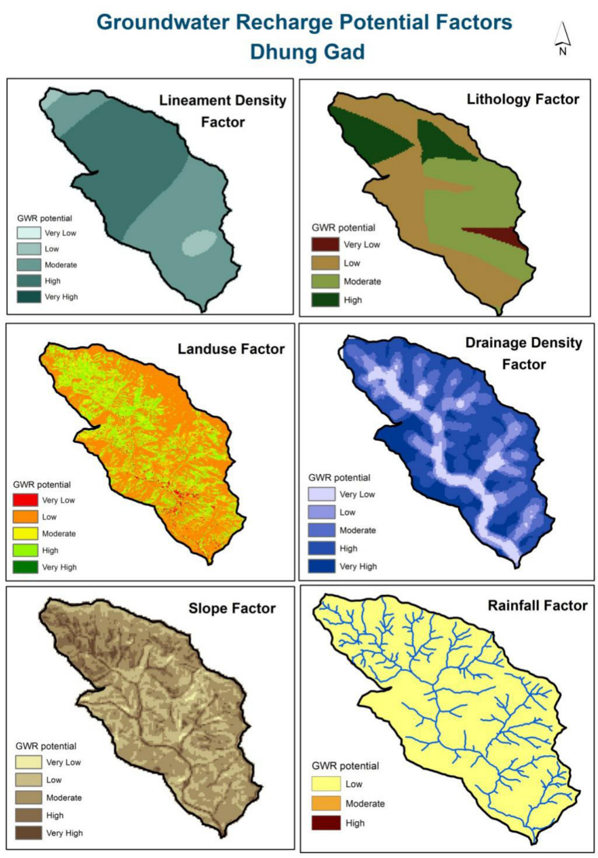

Figure 3a. Groundwater recharge potential factors in Dhung Gad, Baitadi

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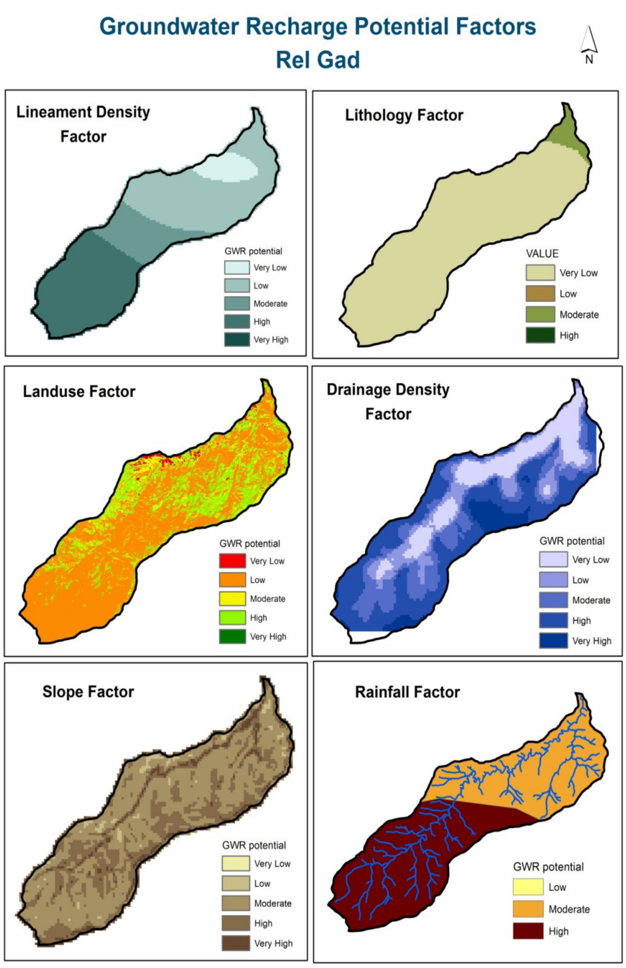

Figure 3b. Groundwater recharge potential factors in Rel Gad, Doti

4.2 Spatial Distribution of GWR Potential and Location of Springs

The study found that most of the study area is under moderate GWR potential comprising nearly 48% spatial coverage (Table 3). The result shows that only 16.2% of the total area of two watersheds area have very high recharge potentiality while 31 % area falls under very low recharge potentiality. Almost total very high GWR potential is confined to Dhung Gad watershed whereas only 0.2% area in Rel Gad watershed is of very high GWR potential. The spatial concentration of very high GWR potential area is towards the northern part of both of the watersheds (Figure 4). Conversely, the lower GWR potential area is found in the southern part of Dhung Gad but the north-western part of Rel Gad watershed.

Table 3. Spatial coverage of GWR Potential in the study area

GWR Potential	Percent		
	Dhung Gad	Relgad	Total
Very High	16.0	0.2	16.2
High	29.3	2.8	32.1
Moderate	31.6	16.3	47.9
Low	19.7	52.8	72.5
Very Low	3.1	28.0	31.1
Source: calculation from GWRP GIS layers			

The identified groundwater recharge potential area map was validated through the location of springs across different potential zones. There is 90 spring occurrence in two watersheds of which, 59 are located in Dhung Gad and 31 are located in Rel Gad (Table 4). It is found that the distribution of existing spring sources is random concerning GWR recharge potentiality. In Dhung Gad, relatively uniform distribution of springs is found in all potential classes whereas, in Rel Gad, the major concentration of springs is in low to very low GWR potential zones. Spring distribution in moderate GWR potential zones of both watersheds is uniform. However, in Rel Gad 77% concentration of springs is in low to very low GWR potential zone and no spring is very high and only 1 spring in high GWR potential zone is found. The location of a fewer number of springs with high flow discharge is noted at the very low GWR potential zone of Dhung Gad. Conversantly, flow discharge of springs located in high and very high GWR potential zone is relatively low.

So far as spring source users are concerned, 57% HH resides in the moderately to very low GWR potential zone in Dhung Gad whereas, in Rel Gad, nearly 95% of users reside in the same zones. Water stress in Rel Gad watershed in particular is evident which accentuates the proper management of existing recharge potential areas.

Table 4. GWR Potential and Location of Springs

GWR potential	Spring distribution	Percent Share of Spring	Average Discharge	Spring users HH	% Spring users HH
Dhung Gad, Southern Slopes					
Very High	14	23.73	0.43	356	17.3
High	17	28.81	0.21	521	25.3
Moderate	12	20.34	0.52	441	21.4
Low	14	23.73	0.5	555	27.0
Very Low	2	3.39	0.75	183	8.9
Total	59	100		2056	

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Rel Gad, Northern Slopes					
Very High	0	0	0	0	0.0
High	1	3.23	0.11	53	5.3
Moderate	6	19.35	0.19	186	18.6
Low	12	38.71	0.73	412	41.2
Very Low	12	38.71	0.31	348	34.8
Total	31	100		999	

Source: Field survey, 2017-18.

The type of springs based on outflow in the study area show that most springs are an intersection between topography and a geological phenomenon. Common characteristics of springs type are found in the study area which matches springs in other parts of the country [2,9,26]. Among 90 springs, the most common type is a depression or contact springs comprising 75% (Table 5). However, their location regarding lithology is variable. Of the total springs in Rel Gad, 90% are in Phyllite/ Phyllite Quartzites area whereas only 2 springs are located in the same lithology in Dhung Gad. Spatial distribution characteristics of springs regarding lithology and slope gradient show that 63% springs are located within 20-35 degree slope while only 3 springs are located in less than a 10-degree slope. Similarly, 61% springs are located within 1000-1500m altitude and 29% are located within 1500-2000m range. Only 9% is located below 1000m altitude.

Table 5. Spring source type and Lithology

Lithology	Depression or Contact Spring	Fissure or fracture Spring	Stream surface flow	Total
Dhung Gad				
Calcacareous Slate/ Sandstones	15	1	8	24
Calcareous Quartzites/ Dolomitic Limestones	23		8	31
Phyllite/ Phyllite Quartzites	2	1	1	4
Rel Gad				
Calcacareous Slate/ Sandstones	0	0	0	0
Calcareous Quartzites/ Dolomitic Limestones	0	0	0	0
Phyllite/ Phyllite Quartzites	28	0	3	31
Total	68	2	20	90

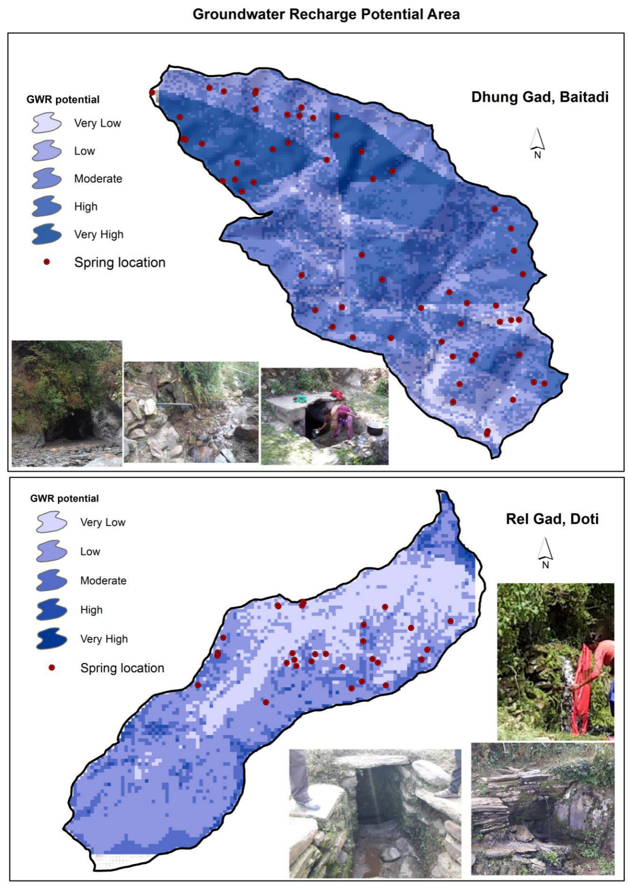

Figure 4. Spatial distribution of GWR potential in the study area

4.3 Data and Method for GWR Potential Mapping: Importance and Challenges

Various statistical methods that were adopted for groundwater potential zone mapping such as weights-of-evidence method [9], multi-criteria decision evaluation method [19], frequency ratio method [3]. Field-based Geological, hydro-geological and Geo-physical surveys using different techniques are used for groundwater exploration and aquifer investigation/ identification [13,37]. Mapping and identification of GWR Potential area using geo-information tools and techniques through analysis of hydrogeological and geological and other information aids such exploration saving time and resources. Geological, hydro-geological and geophysical methods, and related techniques are *in situ* method for groundwater exploration and recharge potential mapping with extensive field investigation [27]. GIS and RS based methods are well accepted for the assessment of availability and status of groundwater resources for developing a map of groundwater typologies. One approach to adopt GIS and RS method for groundwater

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recharge potential mapping is due to readily available data with limited field investigation whereas another approach is to map areas with no or poor field data/sample availability [35.40]. Integrated GIS/RS and quantitative estimation of mean relative recharge for a hydrologic research unit were carried out using the GIS tool based on the mean annual precipitation records [13]. Physical attributes like surface geology, soil type, impervious land cover (buildings, roads, etc,)and drainage density were regarded as the most significant influence and primary indicators for assessing recharge.

Collection of data on the characteristics of the spring and its catchment for poorly understood spring sources and groundwater systems are also emphasized [22]. Importance of groundwater recharge potential and spring mapping is highlighted in several studies [3,13,22,25]. Such studies help to address location-based water management planning and new infrastructure development, maintaining and regulating water supply and surface and groundwater flow. The GIS/RS based GWR potential mapping result may be useful for decision-makers to formulate appropriate groundwater management strategies in the data-poor and economically poor nations.

A study carried out in the central middle mountain region of Nepal applying weighted evidence method with eleven influencing factors in a GIS environment and the validation of groundwater spring potential in the field concluded that the method can be replicated in a similar biophysical environment, where the hydro-geological or geophysical surveyed data is not available [17]. Gentle slope, low relative relief, high flow accumulation, north- and east-facing slopes, denser lineament density, altitude class of 1500-2500 m, high vegetation density, and forest demonstrated a higher likelihood of spring occurrence which implies availability of groundwater recharge potential. Groundwater potential mapping in the Nepalese context is limited particularly in the hill and middle mountain regions. The studies carried out so far in the country have included both controlling and influencing factors like lithology, drainage density, land use/land cover, lineament density, slope, and precipitation [28]. The studies on groundwater mostly carried out in the Southern plain (Terai) region of Nepal have focused on availability and use of groundwater, groundwater aquifer and geological formations, groundwater environment, recharge potential, and the factors that have control over it [36]. Most of these studies have concluded varying depths and amounts of availability of groundwater in the country. Very few studies have been carried out in the far western hill and mountain region of the country [11,20,23]. These studies have outlined the limitation of geo-hydrological data and detailed geo-lithological surveys and maps, which is imperative for understanding the complexities of the geo-hydrological process of springs and spring water recharge potentials [20].

5. Conclusion

Two major approaches to GWRP mapping and analysis are prevalent in contemporary groundwater recharge research namely, a data-driven method with an intensive desk study, and site-specific observation and exploration with extensive field survey.

A very high GWR potential zone is located downstream in the northern slope (Rel Gad) but is located upstream in southern Slope (Dhung Gad). In Rel Gad watershed annual average rainfall is higher and has lower slope but spatial coverage of high/high GWR potential is low as compared to Dhung Gad only because it is located in the northern aspect of a similar slope gradient. Springs distribution is relatively uniform in all GWR Potential classes in Southern Slope but clustered to moderate-very low classes in Northern Slope. The average spring discharge is relatively higher in Northern Slope but lower in Southern Slope. Variable GWR potential in two watersheds with relatively similar altitude zone, land cover land use, slope, and geology but the difference in rainfall e.g. Southern slope with less rainfall has a large area under high to very high GWR potential while and northern slope with higher rainfall has a very limited area under the same. This finding implies that a combination of factors play a different role in different geographical setting and groundwater recharge potential is localized in the area of complex geographical and geological setting.

The finding also implies the importance of high-resolution spatial data and detailed study of the smaller spatial unit for GIS/RS based GWR potential research. Both of these are perhaps the utmost limitation in current time particularly of spatial data of different physical factors and spatial scale at which the recharge potential is mapped. The GWR potential mapping is, therefore, important for planning and management of water security. Such mapping apprehends to spatial coverage gaps and helps manage and monitor resource development and use. Proper management of recharge potential area and spring water sources will direct the future water availability in the watersheds to fulfill the increasing water need of the communities.

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