LUPINE PUBLISHERS

Demarcation of Groundwater Prospect Zones in Lower Reaches of Daraudi River Basin, Western Nepal

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Abstract

In spite of the fact that Nepal is rich in water resources, majority of the mountain settlements faces scarcity in domestic water supply. Springs are the primary source of water for the sustainability of livelihood in mountain. The springs are becoming dry and the water availability has been further decreased leading to migration of entire village in some cases. Therefore, there is need to identify groundwater prospect area for further exploitation. This study proposes the methodology for delineating the groundwater prospect zone in the mountainous terrain at lower reaches of Daraudi River basin in west Nepal. Spring inventory was carried out collecting relevant information like spring type, discharge etc. together with surrounding geology and geomorphology. Thematic layers of different parameters like geology, slope, land use, geomorphology, drainage density, lineament density was prepared. Based on the field condition, weight and rank values were assigned to respective themes and their classes. Groundwater prospect map was prepared through weighted overlay of the thematic layers. The map was verified through comparing with the spring inventory and it is observed that most of the springs fall in high groundwater prospect zone while few in moderate zone and negligible in low prospect zone. This suggests that the methodology adopted to groundwater prospect map in this study well reflects the field condition and hence can be replicated in other mountain region with similar geologic and geomorphic as well as climatic condition.

Keywords: Groundwater Prospect; Nepal Himalaya; Hilly region; Factor Maps; GIS

Introduction

Nepal is mountainous country that has 83% area covered by mountainous and hilly region while 17% area is covered by plain land of Terai. Groundwater is sufficiently available in the Terai region while the mountain aquifer is least explored in spite of its great significance for sustaining the livelihood of people. The rapid increase in human population has increased the groundwater resources demand primarily for drinking and then for agricultural purposes. Delineating groundwater prospect zones in mountainous area is primary task for assessing the groundwater occurrence leading towards further site-specific exploration using geophysical methods followed by drilling. Remote sensing and Geographic Information System (GIS) are widely used in identification of the groundwater prospect zone and recharge areas considering geomorphology, slope, aspect, lineament density, drainage density, lithology, land use etc. as effective factors. Groundwater prospect mapping using remote sensing and GIS has been carried out by many authors considering various parameters [1-8]. The groundwater

occurrence depends on the porosity of the media. Higher surface runoff is depicted by high relief, steep slopes and high drainage density, whereas low drainage density, high lineament density and topographical depressions are favorable for increased infiltration.

Present study has been carried out in the lower reaches of Daraudi River basin in west Nepal that occupies an area of 32 km² (Figure 1). The people in the region are heavily relying on the natural springs to meet their domestic water demand. The area was severely affected by Mw7.8 Gorkha earthquake of 2015 and there was pronounced impact to the groundwater [9]. Further, the effect of climate change at global scale is also expected to have significant effect to the water resources of Himalayan region [10-13].

The main objective of the present study is to delineate groundwater prospect zone in the study area. The method applied could be useful while acquiring similar task in terrain with similar geological, geomorphological and climatic condition. This map

can be used to carry out detailed groundwater investigation in the high groundwater prospect zone to identify suitable site for drilling water well for enhanced supply of the domestic water demand of the people living in the area. The method followed in this study is especially important in view that the weight and ranks for different parameter maps are not standardized because it could

vary for different watersheds in the hilly region of Himalaya that is represented by varying geological, geomorphological and micro-climatic conditions. Therefore, the present research output is aimed to establish groundwater prospect zoning in the mid-hill region of west Nepal.
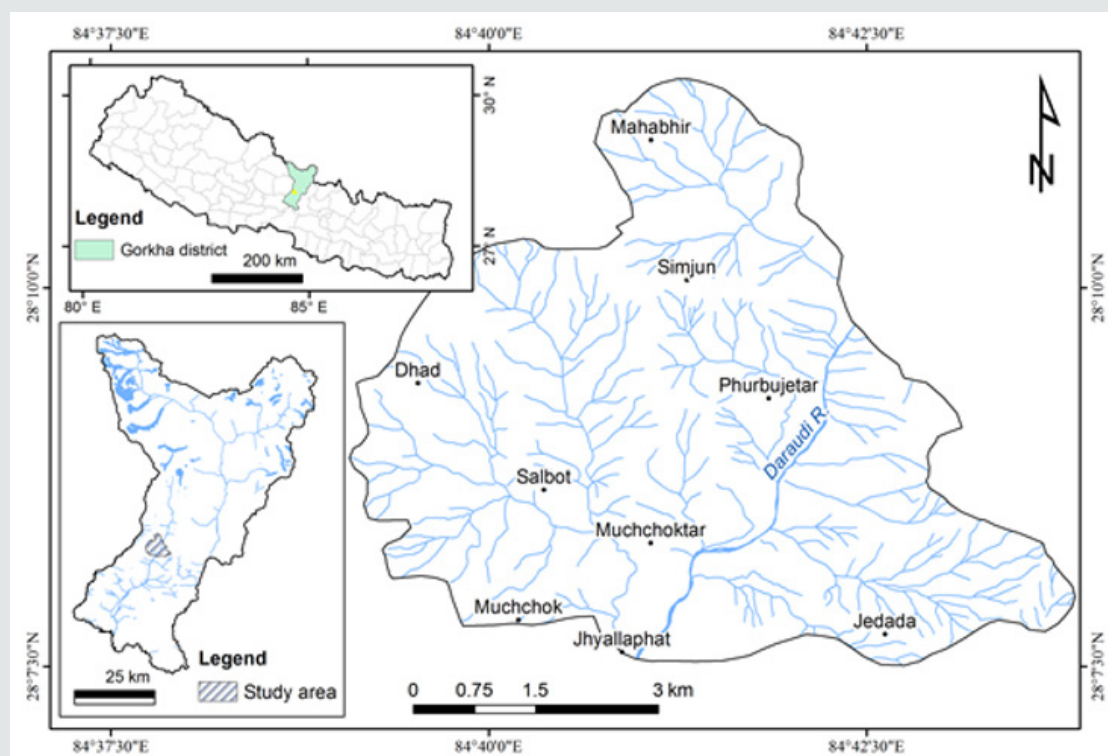

Figure 1: Location map of the study area.

Materials and Methods

The study was initiated through the collection of geological map, topographic maps and satellite image to extract basic information of the study area. Field questionnaire and checklists for data collection was prepared. Geological hammer, GPS (Garmin Colorado 300), and dilute hydrochloric acid (HCL) were used in the field for geological study and spring inventory. The dilute HCL was used to confirm the presence of calcium carbonate in rocks while the coordinates of spring locations were obtained through the GPS measurement. Likewise, the hammer and compass were used to identify the rock type and measure the orientation of rocks. Spring inventory with relevant data collection was carried out using the field check list and information on the spring discharge fluctuation as well as the use of spring was collected through questionnaire survey. In addition, geology and geomorphological mapping was carried out and assessed with respect to spring occurrence. The land use map as of digital topographic map of Department of Survey prepared on 1995 was updated with the help of satellite imageries and also in the field. Lineament map was prepared from the visual image interpretation. The primary and secondary

data were compiled to form GIS database. Thematic layers like geology, geomorphology, slope, land use, lineament density and drainage density were prepared. Weights to the thematic layer and rank to classes were assigned based on the field observation. The thematic layers with weights and rank values assigned was overlain using the weighted sum method and the resulting map was classified into three classes, namely high, moderate and low groundwater prospect zone using the equal interval method. This method classifies the range of values of the cells of output map into zones of equal interval. It is common practice that the integrated map are divided into different zones based on the score range [7,14]. The classified map was validated through crossing with the spring occurrence in the area. If higher number of springs falls into the high and moderate prospect zone, it is an indication that the analysis is reasonable and the output map is representing the real field condition. The natural spring occurrence reflects the fact that the area is already having groundwater resources and hence groundwater can be further exploited in the area through drilling wells. There is both trend that the resulting groundwater prospect maps are either validated [1,15] or presented without validation [7, 14,16].

Results and Discussion

Factor Maps for Groundwater Occurrence

Lithology is primary factor to be considered for the groundwater occurrence in an area. Geological study covering the study area has been carried out by many authors [17-28]. The study area consists of two sequence, the Lesser Himalaya sequence and Higher Himalayan sequence separated by Main Central Thrust – MCT (Figure 2a). The geological formations are interpreted to lithological units to ease the groundwater occurrence in the study area. The Lesser Himalaya consists of high-grade metamorphic rock such calcareous quartzite, calcareous metasandstone, psammatic schist, graphitic schist. The Formation 1 of higher Himalaya is exposed in the study area that is consisting of banded gneiss with quartzite. Five lithological units of lesser Himalaya, namely calcareous metasandstone and marble, psammatic schist, calcareous quartzite and psammatic schist, calcareous quartzite and marble, and graphitic schist, are exposed in the study area.

The land use classes identified in the study area are forest, cultivation, bushes, sand and gravel, settlement and water bodies (Figure 2b). The maximum land is covered by cultivation followed by forest, bushes and settlement. Geomorphology has significant implication to the occurrence of groundwater, which is dealt through hydrogeomorphology [27-31]. Geomorphologically, the study area can be divided into low, medium and high dissected area (Figure 2c). The highly dissected area act as a greater runoff and low recharge zone whereas low dissected area has less runoff and greater recharge zone. The maximum area has been occupied by low dissected area followed by medium and high dissected area.
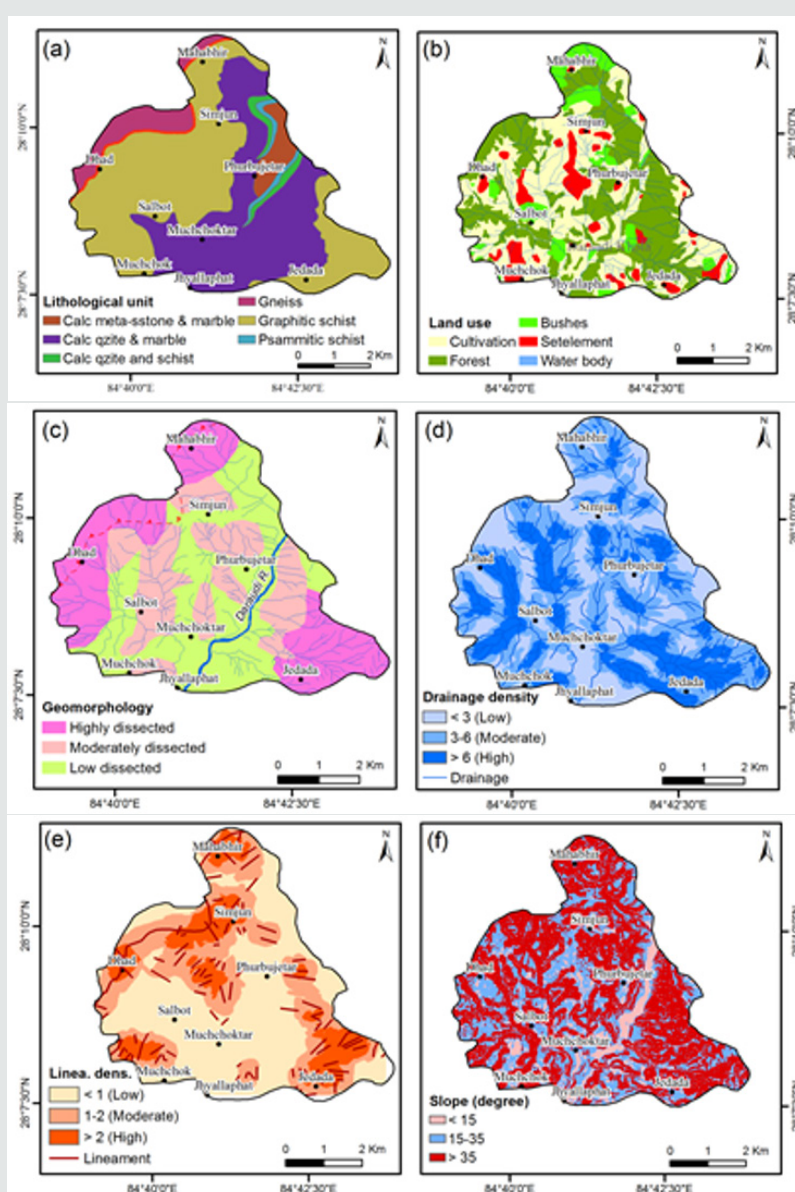

Figure 2: Factor maps used for groundwater prospect mapping: (a) Lithological units; (b) Land use; (c) Geomorphology; (d) Drainage density (km/km²); (e) Lineament density (km/km²); and (f) Slope.

Drainage density is another important parameter for the groundwater occurrence. The higher drainage density reflects greater runoff whereas groundwater recharge is favorable when the drainage density is low. The study area is divided in to three classes, low (<4), moderate (4-8) and high (>12) drainage density (Figure 2d). Lineaments are the linear features that express the zones of weakness in the surface of the earth. The linear features are represented by faults, fractures and joints. Lineament allows the open spaces within the rocks suitable to store water and acts as conduits to transmit the groundwater.

Thus, higher lineament density would increase the chance of occurrence and movement of groundwater, which has been suggested by various studies [32-37]. In the present study, the linear features are interpreted from the satellite image to prepare lineament map for the study area (Figure 2e). Lineament density map has been prepared from the lineament map and classified into low lineament density followed by moderate and high lineament density. The high lineament density mostly lies in the rock exposed areas. Slope is another principle factor that has control in the groundwater recharge and movement. The steep slope cause rapid runoff and doesn't store water easily hence there is sufficient duration for rainwater to percolation when the slope is gentle and surface runoff is low. Slope map of the study area is divided into three classes, i.e. <15°, 15°-35° and > 60° as presented in Figure 2f.

Spring inventory was carried out to assess natural groundwater discharge so that the occurrence of groundwater in different geophysical condition, like geology, land use, geomorphology, drainage density, lineament density and slope could be evaluated. Twenty-eight springs were observed and mapped in the study area (Figure 3).
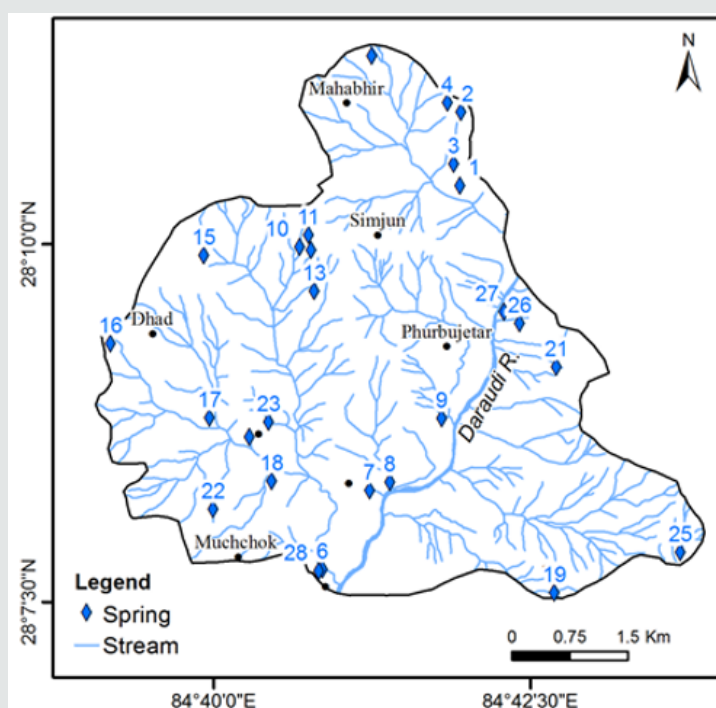

Figure 3: Spring inventory in the study area.

Most of the springs are depression and fractured types [38]. Out of 28 springs, 16 are of fracture type, 10 springs are of depression type and only one is of contact type. The depression type of springs is distributed mostly in the colluvial deposits overlying the bed rocks while the jointed rocks are represented by fracture springs.

Preparation of Groundwater Prospect Map

In order to demarcate the groundwater prospect zones, the factors maps were assigned weight values, while rank values were assigned for the classes of each factor maps depending upon its influence on groundwater occurrence. As per the importance of these parameters to the occurrence of groundwater, the total weight (100) was distributed among the six factors. Likewise, rank for each class of the factor maps was defined in the range of 1 to 3; where 1 represents the lowest suitability and 3 as the highest suitability for groundwater occurrence (Table 1).

Weighted overlay method was carried out to integrate the factor maps to demarcate groundwater prospect zones and the resulting output map was further classified into three classes namely, low, moderate and high prospect zones using equal interval method (Figure 4). Most of the study area is represented by moderate prospect zone (35.43%) followed by high prospect zone (33.24%) and low prospect zone (31.33%). The classified groundwater prospect zones were validated through crossing with the spring occurrences. Out of 28 mapped springs, 16 springs fall on high groundwater prospect zone, 10 springs fall on moderate prospect zone, while only 2 springs fall in on low groundwater prospect zone (Figure 5).
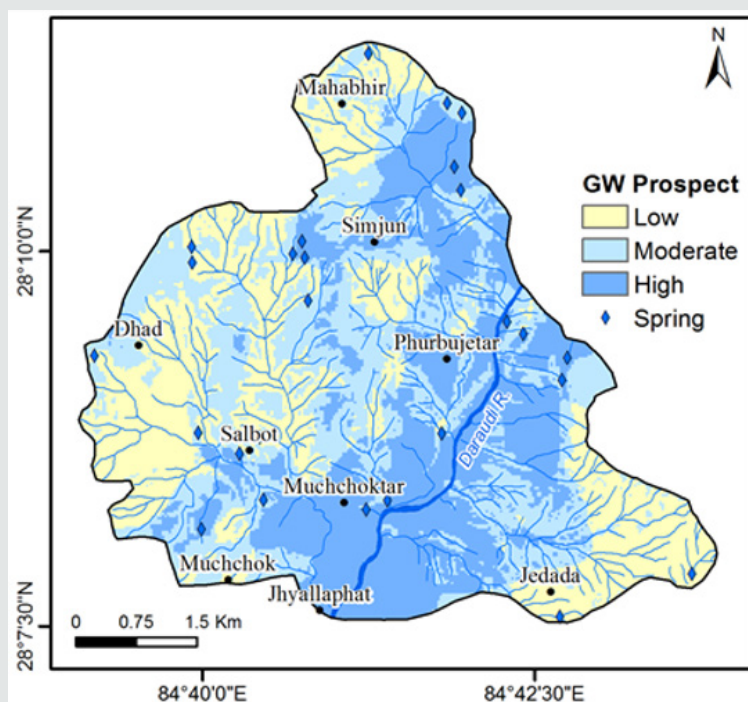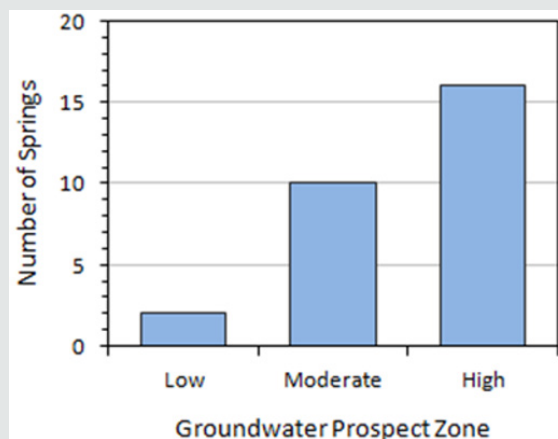
Figure 4: Groundwater prospect map.

Figure 5: Spring occurrence in different groundwater prospect zones.

Table 1: Weight and rank assignment to thematic layers (Factor maps).

S. N.	Parameter	Classes	Weight	Rank
1	Geology	Calc quarzite and marble	25	3
		Calc quartzite and schist		1
		Calc-metasandstone and marble		2
		Graphitic schist		1
		Psammitic schist		1
		Gneiss		2
2	Drainage density	Low	10	3
		Moderate		2
		High		1
3	Slope	Gentle (< 15o)	15	3
		Moderate (15o- 35o)		2
		Steep (> 35o)		1

4	Land use	Forest	10	3
		Bushes		2
		Cultivation		3
		Water body		3
		Settlement		1
5	Geomorphology	Low dissected	25	3
		Moderately dissected		2
		Highly dissected		1
6	Lineament Density	Low	15	1
		Medium		2
		High		3
Total			100	

Different authors have used different combinations of factor maps. Some authors have used five thematic layers of drainage density, lineament density, slope, land use/land cover and lithology [39]. However, some authors have used ten factors like, altitude, average slope, geology, lineament density, geomorphology, soil type, land use/land cover, mean annual precipitation, drainage density, and distance from river [15]. In the present study six factors (Geology, drainage density, slope, land use, geomorphology, and lineament density) that have pronounced control on the occurrence of groundwater in the area have been considered. Likewise, there are various methods for assessing groundwater prospect zones, like quantitative, semi-quantitative and knowledge driven [15,40-48]. In the present study, the knowledge driven technique has been used, which yields reasonable output as thorough knowledge of the field area is achieved during the field investigation.

Conclusion

The study area consists of Lesser Himalayan and Higher Himalayan rocks. The Higher Himalayan rocks are characterized by Formation I represented by banded gneiss and the five litho-units of the Lesser Himalaya represented by Calcareous Metasandstone, Marble, Schist and Quartzite. Total of 28 springs were mapped during spring inventory in the study area. Lithology, land use, geomorphology, drainage density, lineament density and slope were considered as the controlling factors for groundwater occurrence in the study area. The factor maps were assigned weight and rank values to obtain score of each map then integrated to obtain groundwater prospect map for the study area. The resulting map was validated using and 28 springs that were mapped. The high prospect zone consists of 16 springs, moderate prospect zone consists of 10 springs and low prospect zone consists of only 2 springs. The groundwater prospect zones demarcated in the present study reasonably represents the field condition of groundwater occurrence and the map can be used for detailed exploration at specific site for groundwater exploitation to meet the growing demand of water in the area. This is specifically important in view of climate change that is supposed to change the future precipitation pattern and depletion of groundwater table thereby limiting the water availability through natural springs and streams.

Further, the method proposed to assess groundwater availability in the mountainous terrain of west Nepal can be replicated in other areas of the region.

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