Characterization of Groundwater Potential of Sindh Watershed Western Himalayas

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Abstract

Water resources in western Himalayas (Kashmir valley) are irregularly distributed in space and time. Effective utilization of the water resources is an imperative task due to climate change. Assessing the potential zones of groundwater recharge is extremely important for the protection of water quality and the management of groundwater systems. Sindh watershed northwestern part of Kashmir valley, is examined in this study to assess its groundwater resource potential. Remote sensing and the geographical information system were used to integrate five contributing factors: lithology, landuse-landcover, lineaments, drainage, and slope. The weights of factors contributing to the groundwater recharge are derived using satellite data, geological maps, land use database, and field verification. The resultant map of the groundwater potential zone demonstrates that the highest recharge potential area is located towards the downstream regions in the basin because of the high infiltration rates caused by alluvium and cultivated land use in these regions. In contrast, the least effective recharge potential area is in upstream regions due to high slope and low infiltration of hard rock lithology.

Keywords: Landuse/ landcover, alluvium, GIS, landsat, Sindh, lithology, lineament

Introduction

Water resources in the Kashmir (western Himalayas) are important source of fresh water to millions people (Jeelani *et al.,* 2008), used for different purposes including drinking and irrigation (backbone of economy). Due to climatic variations there is a decrease and variation in the snowfall and river flow leading to water shortage which has laid more emphasis on groundwater resources (Jeelani *et al*., 2013). Because of its continuous availability and admirable natural quality, it becomes a significant source of water supply in both urban and rural areas of any country (Todd and Mays, 2005). It also helps in poverty assuagement and decrease, i.e., can be delivered directly to the poor community far more cheaply and quickly than the canal water. Of the total of freshwater appraised to be present on the earth, around 22 % of it exists in the form of groundwater, and it constitutes around 97 % of all liquid freshwater available which is used for human consumption (Foster, 1998). But, the mismanagement of groundwater resource to supply ever increasing petition finally leads to water shortages and pollution (De Villiers, 2000; Tsakiris, 2004). Therefore, unsustainable groundwater use is becoming increasingly obvious and the key concern, particularly in developing countries (Todd and Mays, 2005). People have to use water competently in afrugally sound manner for present and future generations, since it is a very limited resource. To do so, implementing advanced geospatial tools are very vital to continuously assess and monitor the groundwater resource status periodically. Recently, digital satellite data can provide quick and useful baseline information about the factors controlling the occurrence and movement of groundwater. Information regarding the geology, land use, land cover, drainage, lineaments and others factors controlling groundwater can easily be retrieved freely (Bobba *et al*., 1992; Meijerink *et al.,* 2000). However, all the controlling factors had rarely been studied together because of the non-availability of data and integrating tools. Now days, geospatial tools have become as an important tools for accomplishing spatial data and decision making in several areas including engineering and environmental fields (Stafford, 2008; Goodchild, 1993; Hsin-Fu Yeh *et al*., 2008). Remote Sensing and Geographic Information System are among those geospatial tools, i.e., are important for investigation of capacious hydrogeological data and for the imitation modeling of complex features ((Hsin-Fu Yeh *et al.,* 2008; Watkins *et al.,* 1997; Gogu *et al.,* 2001; Gossel *et al.,* 2004).

Very restricted information, such as precipitation, river flux, hydro-geological properties, groundwater consumption, and groundwater recharge, is available for Kashmir valley area of Jammu and Kashmir. Jeelani *et al.* (2005, 2010, 2011, 2014) carried out the study on the chemical quality and recharges of the springs towards southeast of the Kashmir Valley and suggested that congruent carbonate dissolution (calcite dissolution, dedolomitization) and incongruent silicate weathering were found to be the dominant processes controlling the groundwater chemistry and snowmelt is the dominant contributor of groundwater recharge. Hydrogeochemical assessment of groundwater in Kashmir valley (Jeelani *et al.,* 2011) suggested that carbonate dissolution is the dominant source of major ions followed by silicate weathering and ion-exchange processes.. The characterization and planning of groundwater resources is particularly difficult for the mountain area of Kashmir valley. Water resources in the Kashmir valley are becoming increasingly insufficient due to economic development. The declining groundwater level in the mountain area is an indication of the decrease in groundwater resources (Yeh *et al.,* 2007). In this study an attempt was made to evaluate the groundwater potential of Sindh watershed. The Sindh watershed was selected because it is important watersheds in Kashmir valley. The groundwater recharge potential zones are assessed for the Sindh watershed.

The Sindh watershed is an upland mountainous catchment of River Jhelum in the western Himalayas, which lies between latitudes 34° 00´ and 34° 20´ N and longitudes 74° 40´ and 75° 20´ E towards south-western part of Kashmir valley and covering an area of 1585 Km^2 (**Figure 1**).

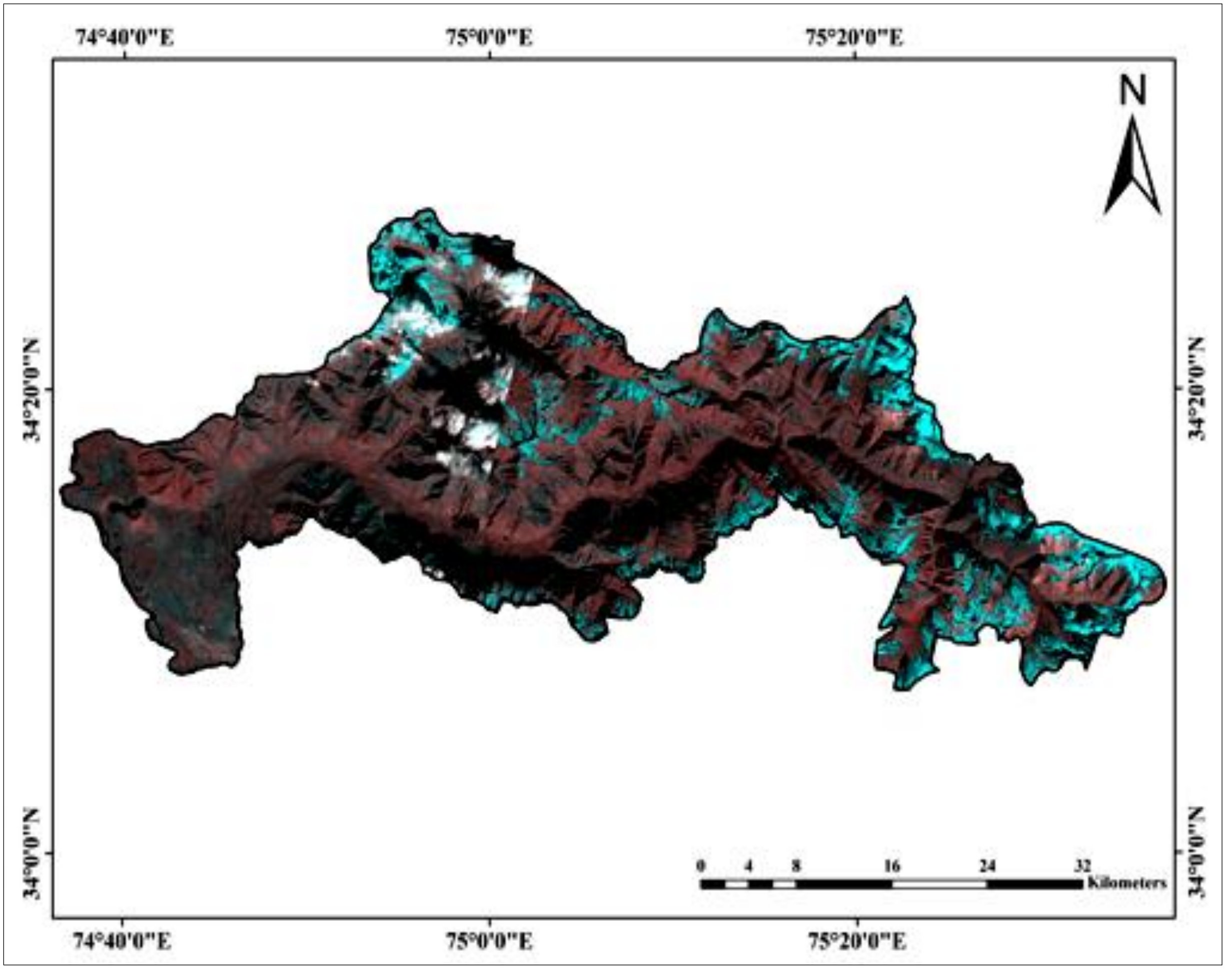

Figure 1: Location map of Sindh watershed

The area experiences a temperate climate and receives average precipitation of approximately 1300 mm $year^{-1}$. Snow is the dominant form of precipitation during winter and early spring seasons and rain during rest of the year. Maximum rainfall of the year is mainly received in month of March and least in November. Daily average maximum temperature is experienced in the month of July about 37°C while as the minimum temperature decreases down to -5°C in January with mean annual temperature of 11°C.

Methodology

Remote sensing technology, such as Satellite images (Landsat TM 2016) and Geoeye data from Google Earth (2016), was used in the present study to identify and extract the geological features, topography, and distribution of the rivers in the region. Additionally, the Land Utilization Survey Database, geologic maps, followed by on-site investigation were adopted to quantitatively and qualitatively describe the hydro-geological conditions of the area. The effect of the factors of groundwater recharge and the contact between the factors were examined. Weighting values were allotted according to the on-site situation. The distribution of the groundwater recharge potential zone was determined by matching it with the space integrating function of the geographical information system (GIS). **Figure 2** presents the flowchart of this study.

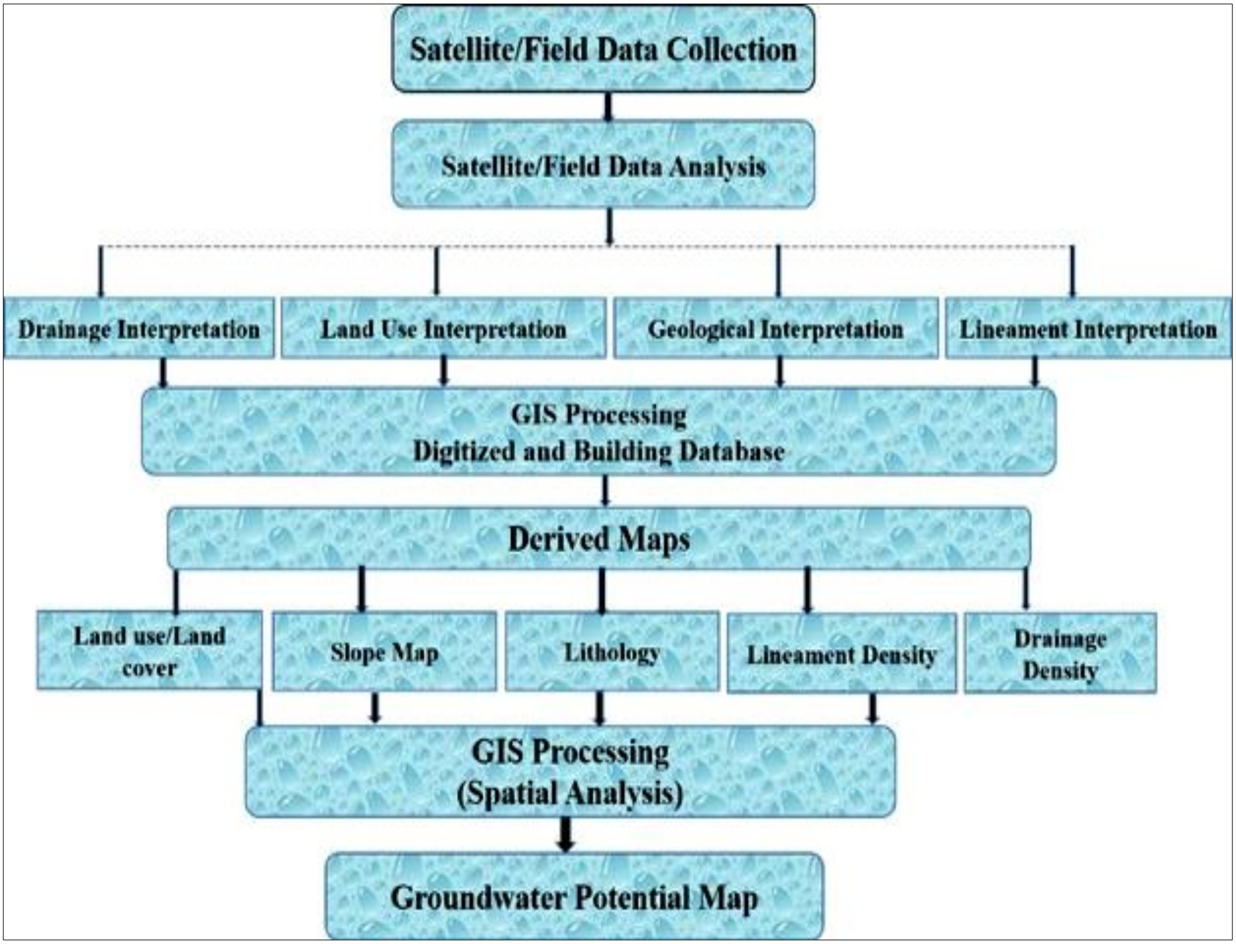

Figure 2: Methodology flowchart for the groundwater potential zone

In this study, the weights of different factors for groundwater recharge potential and the score under various characteristics were evaluated based on the characteristics of the Sindh watershed. This study uses lithology, land use/cover, lineaments, drainage, and slope as the five significant factors affecting groundwater recharge potential. The factors affecting groundwater recharge potential, which are listed in **Table 1.**

Table 1: Factors influencing groundwater recharge classified criteria

Factor	Basis of categorization
Lithology	Rock type, weathering character, joints, fractures
Land cover/land use	Type, areal extent, associated vegetation
Lineaments	Lineament-density value
Drainage	Drainage-density value
Slope	Slope gradient

GIS technology was used to digitize the hydrologic and geographic information, and a fundamental database was constructed. Finally, the spatial analysis function was used to establish the groundwater recharge potential zone of the study area.

Results and Discussions

Evaluating physical and environmental factors controlling groundwater occurrence

1. Geomorphology

The main geomorphic units identified in the area are alluvial plain, gentle slopes/residual hills mountainous ridges, moderately dissected hills, highly dissected hills, river channels, and Glaciated terrains/denudational hills. Highly dissected hills, moderately dissected hills followed by glaciated terrains are the dominant types of geomorphological class in the area **Figure 3.**

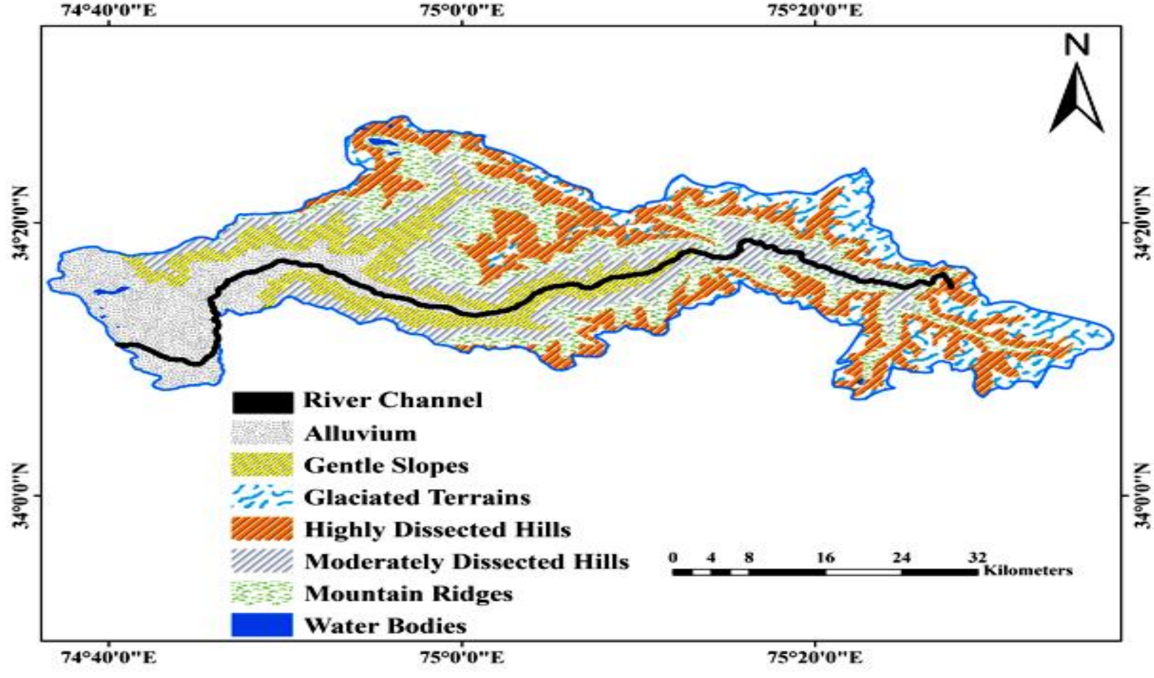

Figure 3: Geomorphology of the Sindh watershed.

As shown in **Figure 3**, groundwater occurrence map, those suitable areas are found with geomorphic class of alluvia plain and gentle slopes because of high infiltration rate. Soumen (2014) also indicated that alluvial plain and gentle slopes have more impact in groundwater occurrence, while the glaciated terrains and mountain ridges areas have shown less impact in controlling groundwater.

2. Lithology

Lithology formations are another important factor controlling the quantity and quality of groundwater occurrence in a given area (Bhuvaneswaran *et al.,* 2015). The study area lithology Figurec4, is dominated by Salkhala (Archean), Panjal traps (carboniferous), Limestone (Triassic Jurassic), Muth Quartzites (Devonian), Agglomeratic Slates (Carboniferous), Zewan Limestone (Permian), Syringothyris Limestone (Carboniferous), Granite and recent alluvial deposits.

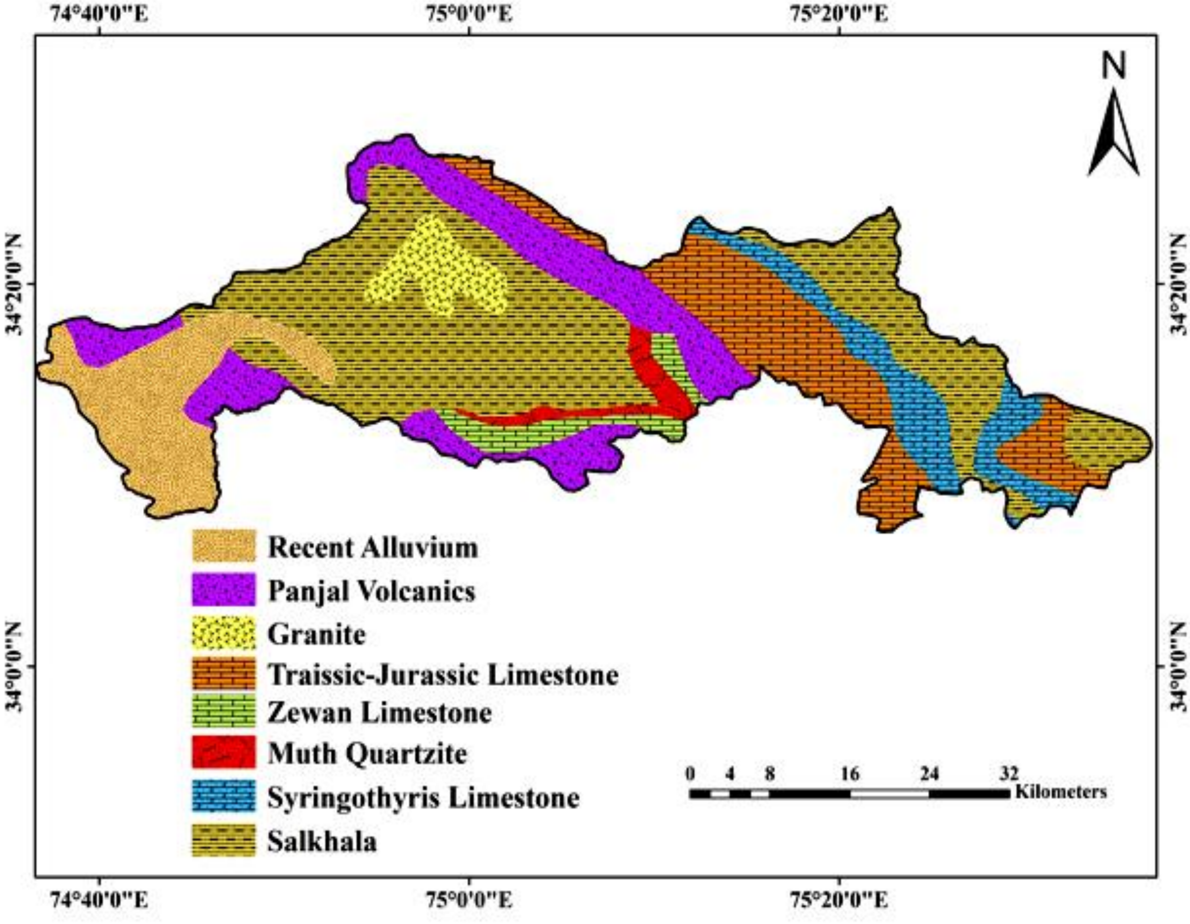

Figure 4: Lithological map of Sindh watershed (Modified after Thakur and Rawat 1992).

The Lithology impacts petro physics of aquifer rocks. The most suitable groundwater potential areas are found in the lithology class of sedimentary and metamorphic rocks because of high secondary porosity and alluvial deposits as shown in **Figure 4**. However, each lithological units doesn't had equal significance in determining and controlling groundwater.

3. Drainage density

The drainage-length density (D_d, L^{-1}), as defined by Greenbaum (1985), indicates the total drainage-length in a unit area, and is determined by:

$$D_d = \frac{\sum_{i=0}^{i=n} Si}{A}$$

Where $\sum_{i=0}^{i=n} Si$ denotes the total length of lineaments (L) and A denotes the unit area (L^2). A high lineament-length density infers high secondary porosity, thus indicating a zone with high groundwater potential (Hsin-Fu Yeh *et al.*, 2008).

Three drainage density categories have been identified and mapped for Sindh watershed as shown in **Figure 5.**

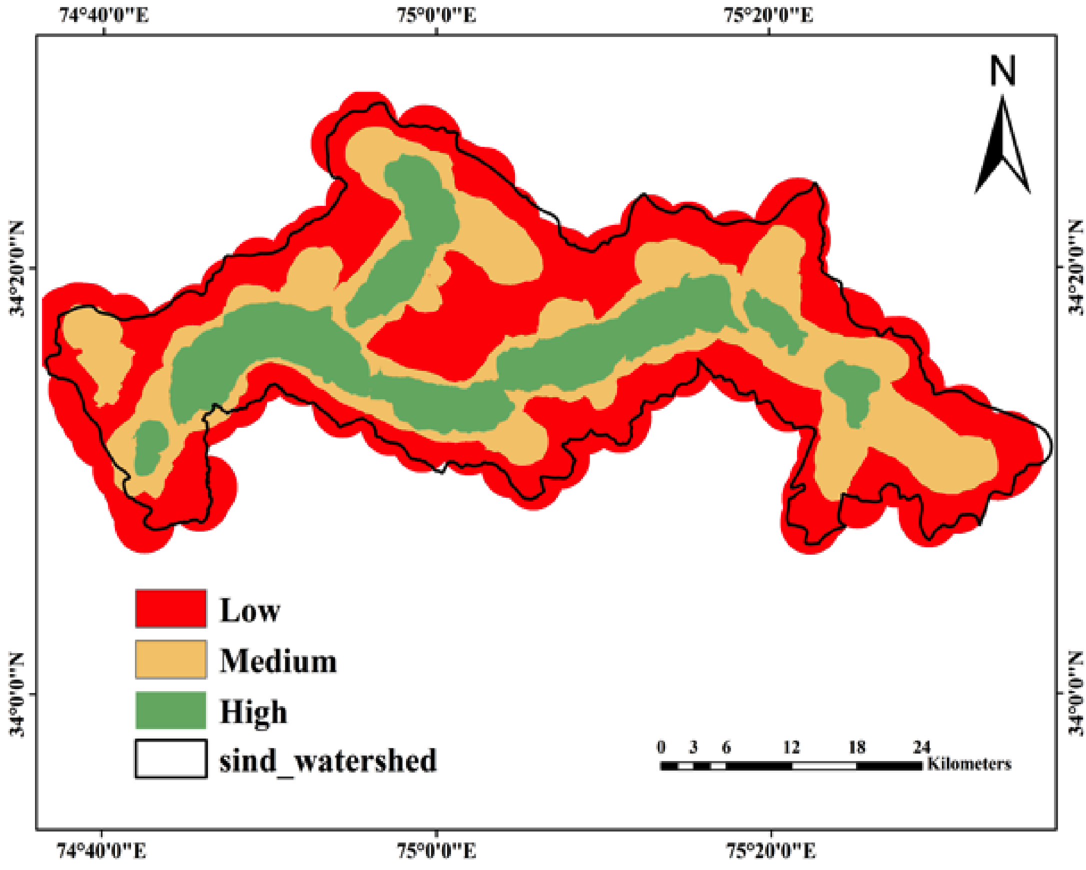

Figure 5: Drainage density map of Sindh watershed.

The very high drainage density areas are found towards the south western parts or lower parts of the study area. On the other hand, the very low drainage density areas are found in the eastern, and north, eastern parts of the study area, while the rest areas within the moderate and low drainage densities are concentrated in the central part of the study area. The high drainage texture indicates highly porous and permeable rock formations, whereas the fine drainage texture is more common in less pervious formations. Structurally controlled drainage is normally seen in southern part of the study area. Drainage texture and patterns are controlled by different litho-units, structure and morphology. In the study area, the drainage pattern is dendritic to sub-dendritic. Groundwater potential is very poor in those areas with very high drainage density/course as it lost majority in the form of runoff. On the other hand, low drainage dens allows more infiltration to recharge the groundwater and, therefore, have more potential for ground water occurrence. Murasingh (2014) noted that low drainage density region are responsible for higher infiltration and it yields in better groundwater potential zones as interrelated to a high drainage density region. On the other hand, high drainage density values are promising for runoff, and hence designates low groundwater potential zone (Aggarwal *et al.,* 2013).

4. Land use/land cover

The land use/land cover of a certain area depends on geomorphology, agro-ecology, climate and human-induced activities. It is one of the factors affecting groundwater occurrence and availability. Supervised image classification was conducted to classify and to identify the type of LULC and six classes were identified. And those are namely built up, forests, plantation area (agriculture and horticulture), barren land, water bodies, wetlands and snow/glacier cover. Landsat satellite image of 2016 with 30 m spatial resolution was used as source of data to drive the LULC map (**Figure 6**).

Singh (2014) stated that LULC information is an important factor in groundwater storage and recharge. The type and nature of LULC on groundwater controlling in order of increment put as:

Forests, cultivated land, barren land and built up. So, forest and cultivated areas (Agriculture and Horticulture) are more suitable for groundwater occurrence because of better infiltration. The degree of cultivation is highly intensified, due to the presence of good groundwater potential.

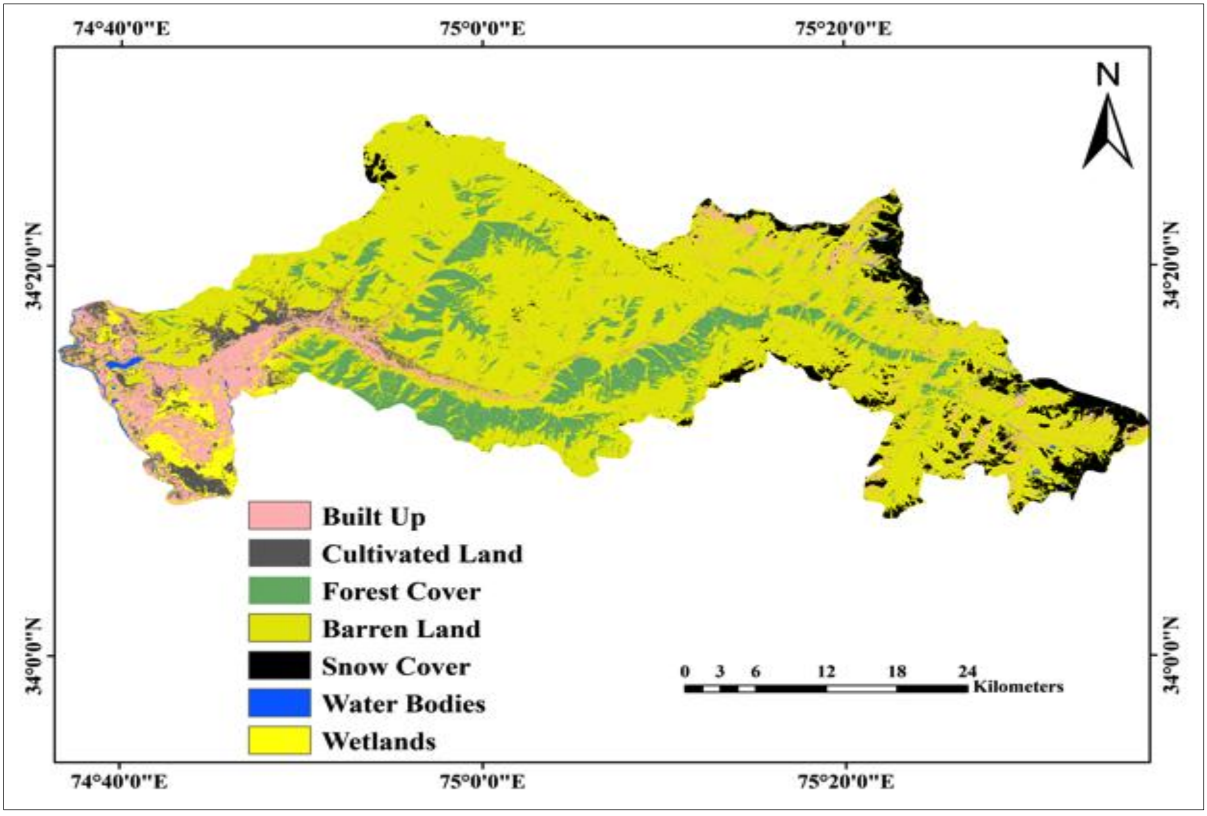

Figure 6: Land use/land cover of Sindh watershed.

5. Lineament density

The present study used lineament-length density (L_d, L^{-1}) (Greenbaum 1985), which represents the total length of lineaments in a unit area, as:

$$L^d = \frac{\sum_{i=0}^{i=n} Li}{A}$$

Where $\sum_{i=0}^{i=n} Li$denotes the total length of drainage (L) and A denotes the unit area (L^2). A high lineament-length density infers high secondary porosity, thus indicating a zone with high groundwater potential (Hsin-Fu Yeh *et al.*, 2008).

Areas with higher lineament density simplify infiltration and recharge of groundwater and, therefore, have good potential for groundwater development (Bhuvaneswaran *et al.*, 2015). Moreover, areas with gentle slope permit less runoff and have very good potential for groundwater availability (**Figure 7**). The slope increases towards the north east and northern parts of the study area that enables high runoff and poor groundwater recharge. A high lineament length density designates high secondary porosity, thus signifying a zone with high groundwater potential (Al-Abadi and Al-Shamma'a, 2014).

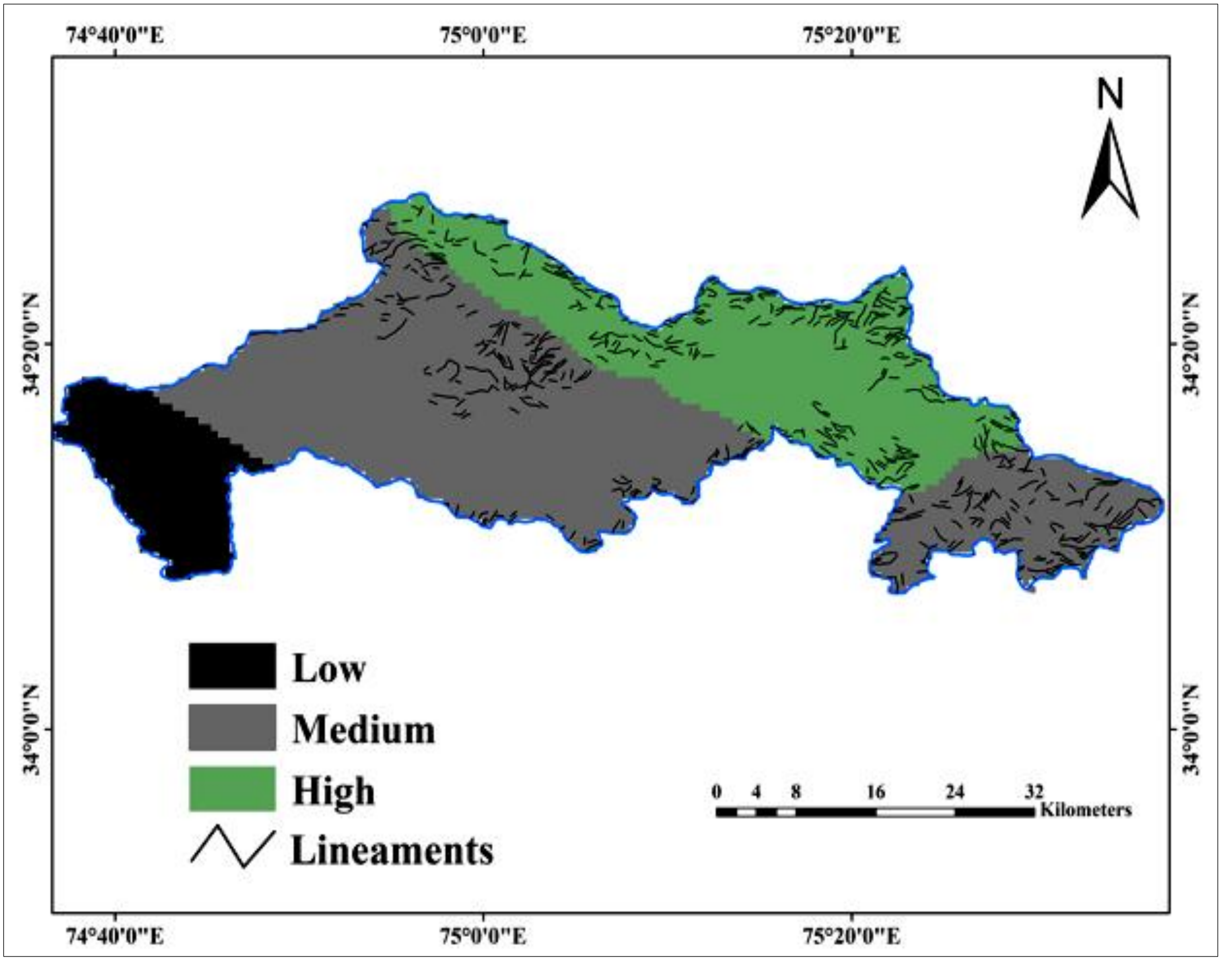

Figure 7: Lineament density map of Sindh watershed.

Slope:

As shown in **Figure 8**, the lower part of the study area is highly covered by built up and cultivating land that is flat having a slope degree value of 0–10 of the catchment. The area with slope values of 10–20 and 20–30 is classified as gentle and moderate of the study area, respectively, which is covered by forests and cultivation land. The area around the north east and north parts of the catchment is steep having a slope value of 30–50 covered by barren and glaciated terrains. Slope is one of the most important factors controlling groundwater occurrence. Flat areas are capable of holding the rainfall and enable recharge to groundwater as compared to steep slope area where water moves as runoff rapidly (Sisay, 2007). The finding further showed that slopes with flat (1-10) and gentle areas (10-20) are more appropriate for groundwater existence as compared to steep because gentle and flat slope areas permit less runoff and have very good potential (Aziz *et al.*, 2016).

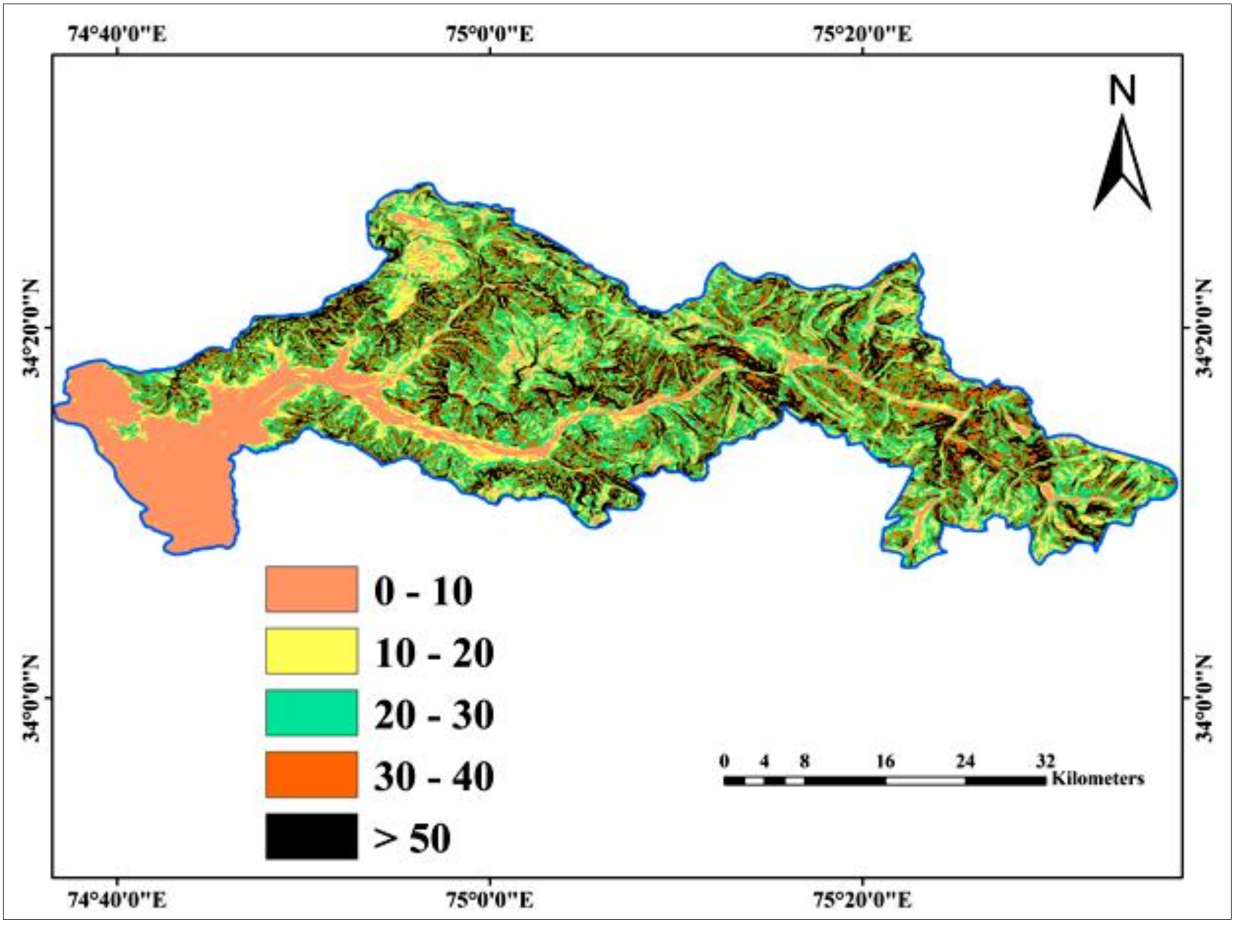

Figure 8: Slope map of Sindh watershed.

Groundwater prospecting and validation:

To recognize groundwater potential zones, factors such as geological structures, lithology, geomorphology, slope, land cover, drainage and others are very important to integrate through RS and GIS techniques (Waikar and Nilawar 2014; Ayele *et al.*, 2015). Groundwater arises within different hydrogeological environment, and topographic settings that control the groundwater dissemination and expansion for different purposes (Tesfaye

2010). For this study, the groundwater prospect map of the area was done by integrating different thematic layers in GIS environment (**Figure 9**).

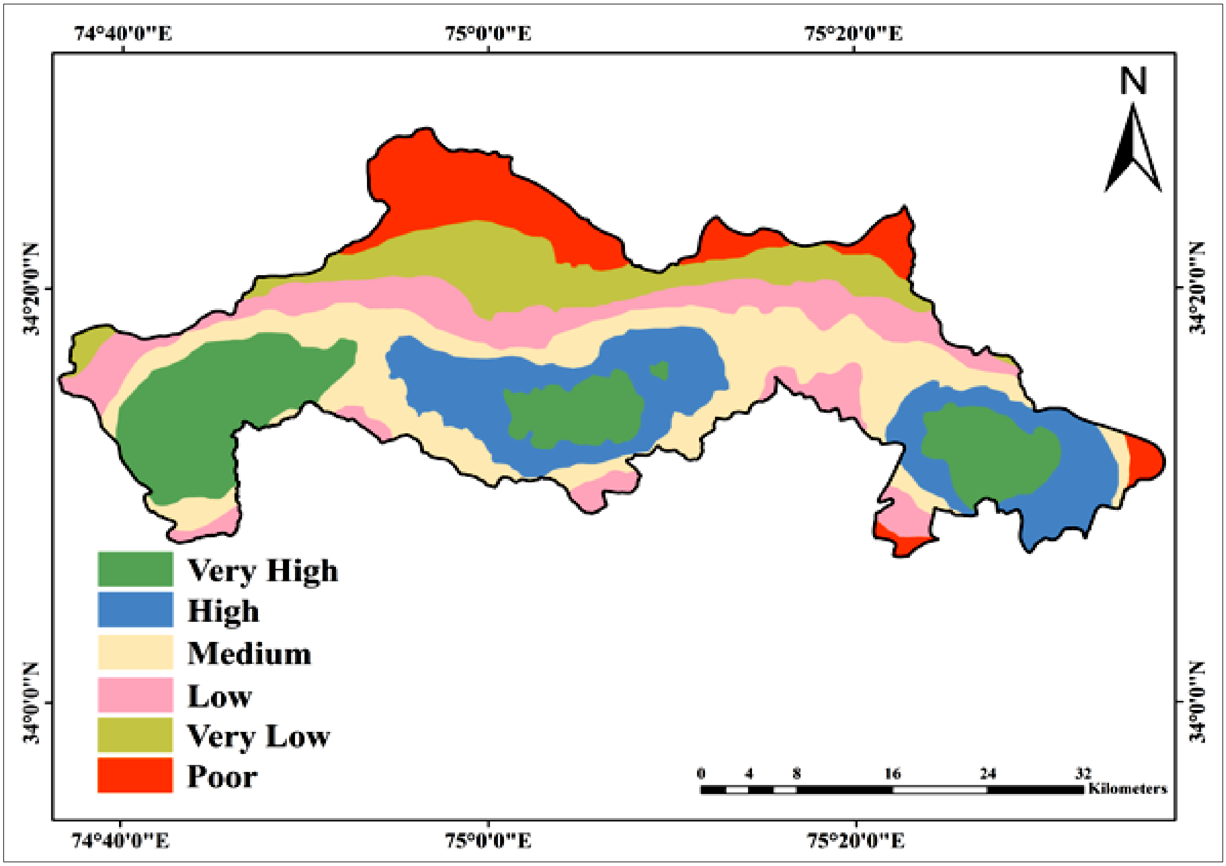

Figure 9: Groundwater potential map of Sindh Watershed

Our results determine that the groundwater recharge potential zone of Sindh watershed can be divided into six grades, namely very high, high, moderate, low, very low and poor based on the examination of the five factors (lithology, land use/cover, lineaments, drainage, and slope) of groundwater recharge potential. Analytical results demonstrate that the excellent groundwater recharge potential zone is concentrated in the downstream region due to the distribution of alluvial plains, gentle slopes and agricultural land with a high infiltration ability. Additionally, the concentration of drainage also helps the streamflow to recharge the groundwater system. The upstream region is less important and is influenced by igneous and metamorphic lithologies with steep slopes.

Conclusion

This paper presents a comprehensive map of unprecedented detail of groundwater potential in Sindh watershed. The results indicate that the most effective groundwater recharge potential zone is located downstream. In this region, the alluvial plains, gentle slopes and agricultural land have a high infiltration ability. Additionally, the concentration of drainage also indicates the ability of streamflow to recharge the groundwater system. The upstream region is least effective for groundwater recharge, mainly due to its igneous and metamorphic rock and steep slope dominance. This study has recognized the interrelationships between the groundwater recharge potential factors and the groundwater recharge potential scores from the general hydrology characteristics of Sindh watershed. Since the groundwater recharge potential is directly linked with percolation, the established scores may be more accurate and objective if the rate of percolation and hydraulic conductivity of each recharge potential factor can be measured in a laboratory or on-site. The groundwater recharge potential zones are established using the grid model, which can be partially modified to study groundwater recharge potential factors (such as changes in terrain and river courses caused by an earthquake, or changes in land utilization) in a small area in the future, thus avoiding widespread re-estimation, which necessities a lot of time and labor. The isotopic tracer technique must be applied to verify the model results in future research. Additionally, the quantity of pumped groundwater should be considered in the groundwater recharge.

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