

RELATIONSHIP BETWEEN DEM DERIVED LINEAMENTS AND SPRING OCCURRENCE IN A HIMALAYAN CATCHMENT

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ABSTRACT

Groundwater mapping in mountains is quite complex, tedious and cumbersome work as aquifers are very localized and discrete in nature. Besides, sparse groundwater level monitoring networks results in poor representation of groundwater status in the area. Hence, natural springs emerging in the area are the only indicators to understand and monitoring local groundwater quality and quantity over space and time. Groundwater movement is largely governed by the local geology. Various linear features viz., joints, fractures, faults, cliff, valley, ridges etc. are represented through lineaments. In the present study, modern remote sensing & GIS tools are employed to extract lineament from Cartosat DEM. Study of lineaments is more important as it not only define the tectonic control of the area but also control the groundwater movement in the mountains. The present study aims to explore the relation of lineaments to the groundwater prospect of the mountains through the occurrence of springs. A total of 261 lineaments were extracted from Cartosat DEM using LINE module of the PCI Geomatica software. Various characteristics of lineaments viz., lineament density, lineament length, cross dot density, distance of nearest lineament from spring were studied vis-a-vis occurrence of 83 mapped springs in the area. It was revealed that lineament density, lineament length density, and lineament cross dot density has strong positive correlation with occurrence of springs (correlation coefficient, $R = 0.89$, 0.96 and 0.95 , respectively). Furthermore, spring occurrences found to be more in the close proximity of lineaments, which reduces as distance of nearest lineament increases ($R = -0.97$). Such strong relationship manifests the strong control of lineament over the genesis of the spring. Outcome of the study can be utilized to identify the areas having potential of occurrences of springs for developing the conservation plan for their protection and preservation.

Keywords: Lineament, Springs, Remote Sensing, GIS

INTRODUCTION

Springs are the main dependable source of drinking water for more than 50 million inhabitants of the Indian Himalayan region (IHR). Springs are naturally occurring formations and hence common water sources for local community (Mahamuni and Upasani 2011). For this reason, villages in the IHR are often found clustered around natural water springs (Rawat et al. 2018). In addition to this, these springs are the life of several rivers and there is hardly any river which is not fed by springs. Owing to their role in sustaining the river flow, springs are the lifeline of several micro-habitats in the river system. There is increasing evidence that springs are drying up or their discharge is reducing throughout the Himalayan region. The erratic rainfall pattern, seismic activity and ecological degradation associated with land use change for infrastructural development is putting huge pressures on mountain aquifer systems. Various anthropogenic activities are also leading to destruction of the internal hydrological system. For example, (Valdiya and Bartarya S.K 1989), reported a 40% reduction in spring discharge over a 35-year period (1951 to 1986) in the Kumaun Himalaya region. Owing to the deteriorating springs' condition, reportedly, nearly 8,000 villages of north-east states of India are facing acute water shortages (Mahamuni and Kulkarni 2012).

Springs are the natural door of groundwater in the mountain area and considered as the part of groundwater. However, the detailed study of groundwater in the mountain areas is often limited due to non-availability of groundwater level data. In addition to this, the mountain aquifers are very localized and discrete due to topographical reasons such as frequent folds, faults and fractures. Unlike surface water, groundwater movement in the mountains is governed by topography and local geology. Dipping of rocks, line of strike, escarpment slope, directions of fault, fracture, joints are the major factors for governing the direction of groundwater flow, whereas type of rocks, weathering stage, secondary porosity, etc. are the factors responsible for the storage capacity of the aquifer. Cumulative impact of all these factors contribute to the genesis of springs. Mapping of these factors are quite difficult and tedious in mountain area due to rugged terrain and harsh climatic condition.

Remote Sensing (RS) and Geographical Information System (GIS) techniques play a vital role in the field of applied Geology while aiding in the mapping of geological features of the earth's surface. Furthermore, the availability of openly available earth data i.e., Cartosat DEM, SRTM DEM, ASTER DEM etc., have made the watershed analysis very efficient from geological point of view. The linear features, which generally show the zone of structural weakness such as cliffs, fractures, faults, joints etc., are called as lineaments. These lineaments play vital role in defining the genesis of springs in the area. According to the definition of (Wajid et al. 2021), the lineaments are parts of a linear or curvilinear feature with a distant relationship to a surface that may be an expression of a fault or other linear feature symbolizing discontinuity. Mapping of these lineaments is a tedious and a time consuming task as it

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required comprehensive field works. However, the available remote sensing data in combination with various GIS techniques can be used to extract the lineaments of any region for better understanding of the geology and region's response (Mogaji et al. 2011; Nagal 2014). Some of the GIS techniques to be used for lineaments extraction are, Hough Transform (Wang and Howarth 1990), Segment Tracing Algorithm (Koike et al. 1995), Haar Transform (Majumdar and Bhattacharya 1988), and the Lineament Extraction (LINE) algorithm of PCI Geomatica software (Hubbard et al. 2012; Thannoun 2013). The most commonly employed method for lineaments extraction among the above method is LINE algorithm of the PCI Geomatica. The combination of automatic extracted lineaments from these techniques are combined with GIS environment for preparation of various geospatial maps and further analysis of these lineaments. However, the automated extracted lineaments must be correlated with the field data to validate the extracted lineament as the true representation for the structural manifestation of an area (Mogaji et al. 2011). In the present study, lineaments of a Himalayan catchment have been extracted from Cartosat DEM using LINE module of the PCI Geomatica and the correlation between various

characteristics of extracted lineaments and occurrences of natural springs at catchment scale have been studied.

STUDY AREA

This present study is carried out in Birun catchment located in the Udhampur district of the Union Territory of Jammu and Kashmir, India. The catchment, located in the coordinates between 32.88° to 33.04° N and 74.04° to 75.17° E, has an aerial extent of about 123 sq. km and elevation ranging from 545 m to 2159 m above mean sea level (amsl) as shown in the Fig.1. River Birun, a tributary of Tawi River, is a springs fed river as there is no glacier present in the catchment. Therefore, springs plays a vital role in sustaining the flow of the river, particularly in the non-monsoon season. Majority of population of the catchment depends on these springs for their daily water demand. Land use land cover map for the study area has been prepared in Arc GIS and depicted in Fig. 2A. Approximately, 58.55% of the area is agriculture land, 25.8% is forest, 8.9% is scrubland, 4.28% is built-up and remaining 2.41% is water bodies (Fig. 2A).

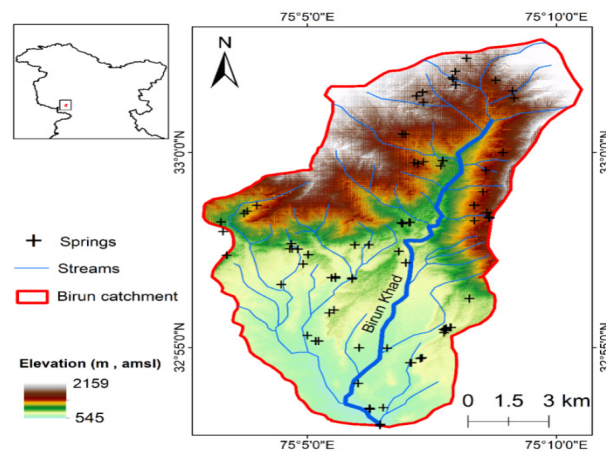


Fig.1: Study area.

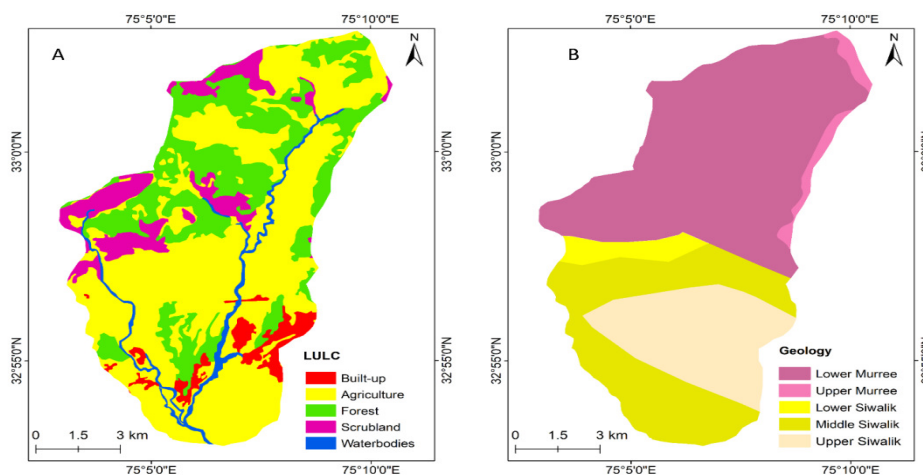


Fig. 2 : (A) Land use land cover map, and (B) represents geology map of area.

Geological map of the study area is obtained from the Bhukosh portal of the Geological survey of India (<https://bhukosh.gsi.gov.in/Bhukosh/MapView.aspx>).

According to the geological map, the study area has been divided into two major groups i.e. Murree and Siwalik group, which are further sub-divided into middle and lower groups as shown in Fig. 2B.

MATERIAL AND METHOD

Cartosat Digital Elevation Model

Among various available DEMs, Cartosat data was used in the present study for lineament extraction. Reportedly, the Cartosat DEM provides most comprehensive geological structural information for Indian provinces (Rajasekhar et al. 2018) in comparison to various other DEMs. Freely available Cartosat DEM (spatial resolution 30 m) can be downloaded from Bhuvan Portal (<https://bhuvan-app3.nrsc.gov.in/data/download/index.php>).

Extraction of lineaments

The stepwise methodology adopted for the lineament extraction in the study is presented in the flow chart (Fig.3). Cartosat DEM was used to prepare different directional hill shade maps of the study area. Hill shade map aids in representing the 2-dimensional surface into 3-dimensional surface, which provides a realistic view of the terrain.

Hill shade function in Arc GIS was used to produce 3D representation of the terrain surface. It is a technique for

visualizing terrain determined by a light source and the slope and aspect of the elevation surface. Eight different directions hill shade maps for the study area were created to make sure the light is coming from eight different directions. The different azimuth angles were used for creating eight different hill shade maps are $0^\circ, 45^\circ, 90^\circ, 135^\circ, 180^\circ, 225^\circ, 270^\circ$, and 315° keeping the Zenith angle 45° . These directional hill shade maps were used in LINE Module of PCI geomatica for automatic extraction of lineaments. LINE module extracts lineaments from an image and convert these linear features in vector form by using six optional parameters RADI (Filter radius), GTHR (Gradient threshold), LTHR (Length threshold), FTHR (Line fitting error threshold), ATHR (Angular difference threshold) and DTHR (Linking distance threshold).

Several lineament maps were generated for various combination of optional parameters and final values of these parameters (Table 1) were adjusted through trial and error to ensure extracted lineament map represents the major and minor geological linear features of study area with reasonable accuracy as observed through Goggle earth. For all eight directional hill shade map, the lineaments were extracted, separately (Fig. 4), utilizing the six different operational parameters listed in Table 1. The lineaments extracted from these different hill shade maps were analysed in GIS environment where in eight different polyline shape file were merged into single polyline file. Duplicate and identical polylines were removed using delete duplicate tool in Arc GIS to avoid the misrepresentation.

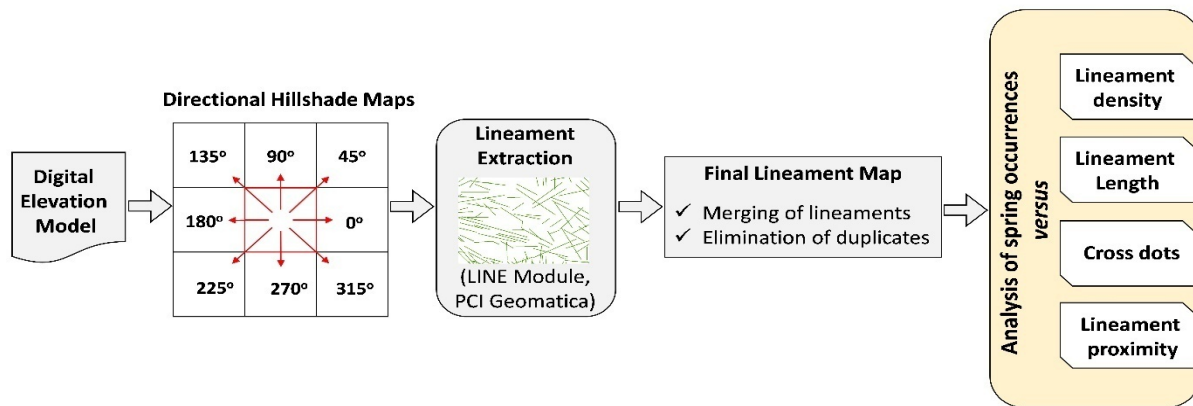


Fig. 3 : Flow Chart of the Methodology.

Table 1: Threshold values for different operational parameters used in extraction of lineament in the study area

Sl. No.	Operational parameters	Threshold value
1.	Filter Radius (RADI)	10 pixels
2.	Gradient Threshold (GTHR)	45 pixels
3.	LTHR (Length threshold)	30 pixels
4.	FTHR (Line fitting error threshold)	3 pixels
5.	ATHR (Angular difference threshold)	30°
6.	DTHR (Linking distance threshold)	20 pixels

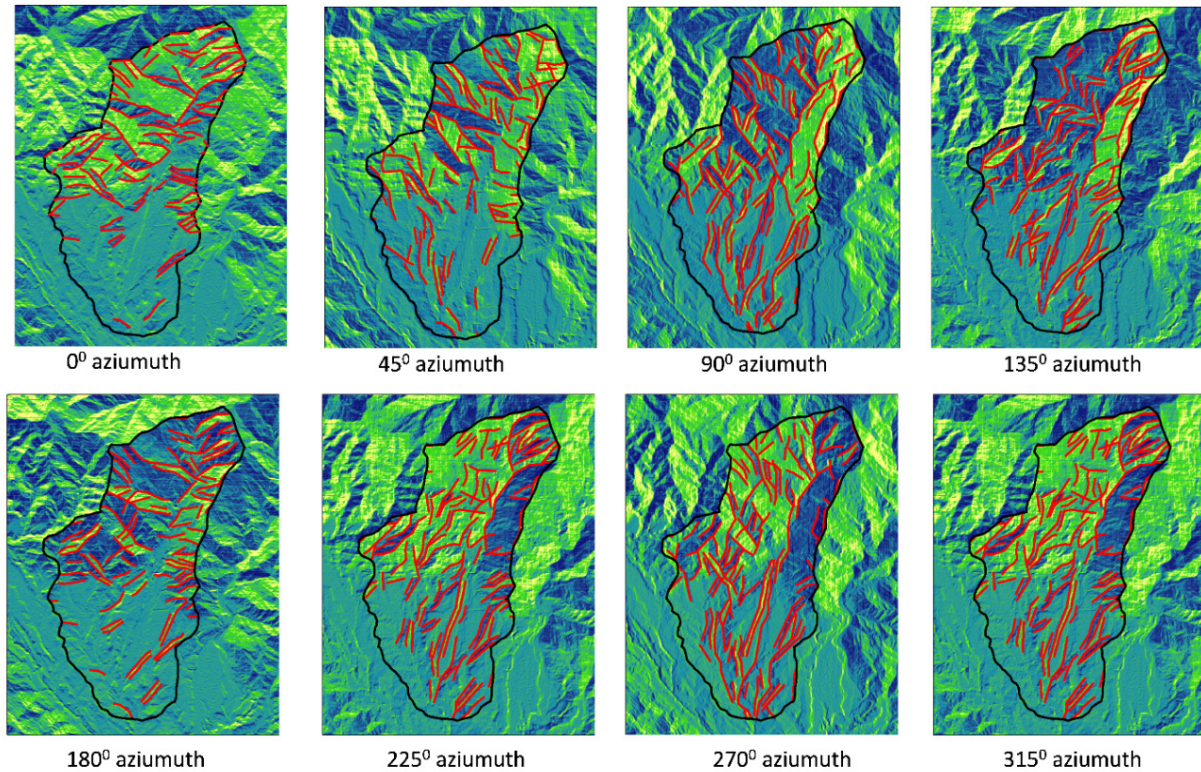


Fig.4: Lineaments extracted for different directions.

RESULTS AND DISCUSSION

Lineament Analysis

Total number of extracted lineaments for eight different azimuth angles are shown in Table 2. These extracted lineaments were used to obtain final 261 lineaments (Fig. 5) after merging of eight different polyline shape file into single polyline file and subsequently removing the duplicate and identical polylines.

Table 2 : Number of lineaments extracted from different hillshade maps.

Azimuth Angle	0°	45°	90°	135°	180°	225°	270°	315°
Number of Lineaments	103	105	129	116	106	125	117	124

To determine the orientation of the lineaments in the catchment Ross diagram was prepared using the Rockwork software. Rockwork frequency per bin method is applied in which the length of the rose petal represents the number of occurrences of azimuth measurements that fall within that bin. From the Rosediagram (Fig. 6) it can be inferred that dominant orientation of the lineament is from North-East (NE) to South-West (SW) direction, however, few sets are oriented towards North-West (NW) to South-East (SE). Direction of lineaments are critical for the study of groundwater flow, as in most cases the orientation of the lineaments create conducive path for the groundwater movement. It can be seen from the Fig 2A that flow paths of

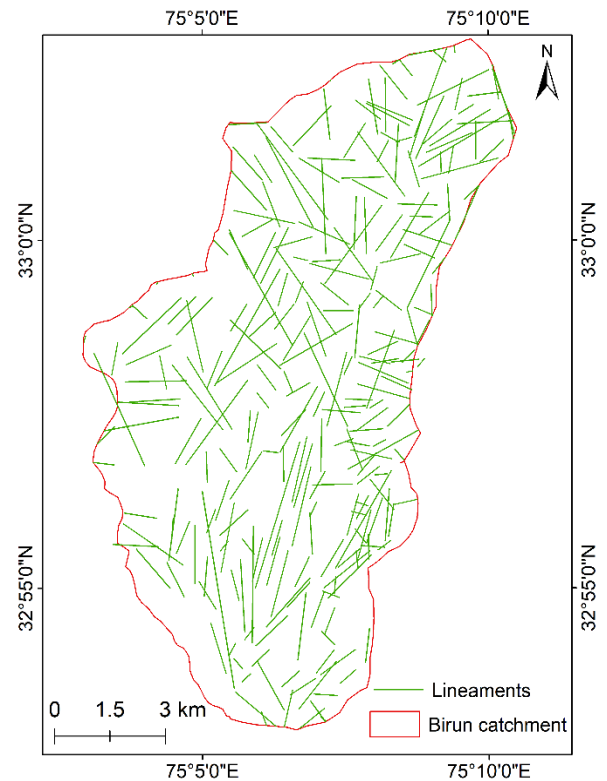


Fig. 5: Final lineament map extracted from Cartosat DEM of the study area.

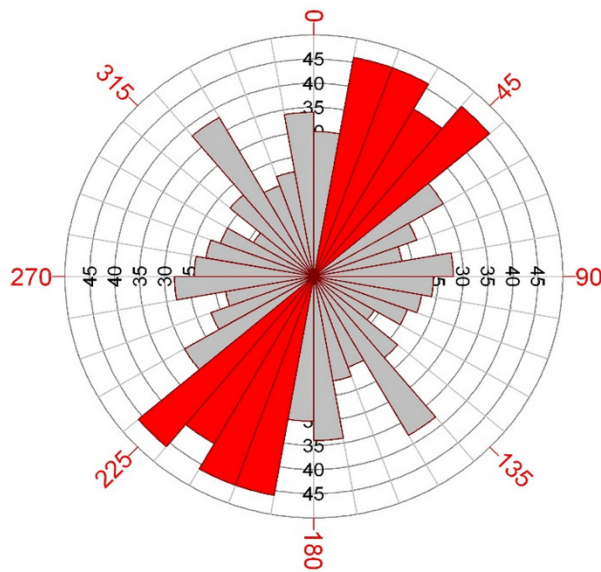


Fig.6: Rose diagram showing the lineament orientation.

main streams in the Birun catchment are from the North-East (NE) to South-West (SW) and from North West (NW) to South East (SE) direction.

Spring mapping

A comprehensive survey for the geo-tagging of the springs was carried-out in the study area. Data collection and geo-tagging was performed using mobile app based survey created using open source tool i.e., KoBo toolbox. Spring discharge was measured by volumetric method using stopwatch and graduated measuring bucket. A total of 83 springs were identified and geo-tagged in the entire catchment. Out of the 83 surveyed springs, 07 springs were either dried or having seasonal discharge (Fig. 7). Mean and median discharge of springs in the catchment were found to be 11.1 lpm and 3.4 lpm, respectively. Here it is worth to note that the spring discharge corresponds to a specific time stamps and for detailed analysis continuous measurement of spring discharge is needed.

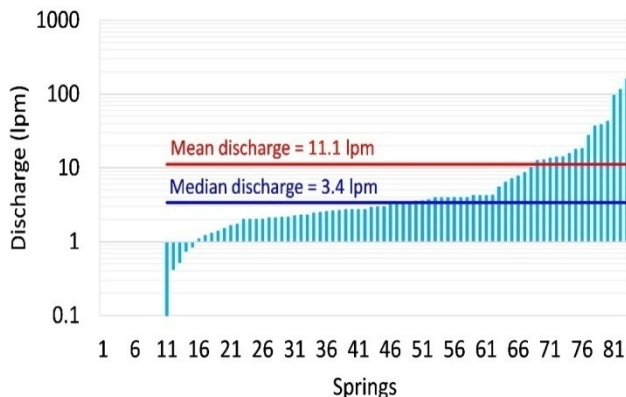


Fig. 7: Spring discharge at the time of survey.

As per the geological map of the catchment, two major formation occur in the catchment, which are further subdivide into sub-groups. Lower portion of the catchment has Siwalik formation and upper part has Murree formation. Murree formation covers area of around 65.4 km² and Siwalik formation covers 57.6 km² area. A total of 39 springs fall in the Murree formation whereas 45 springs were found to be originating in the Siwalik formation (Fig. 8).

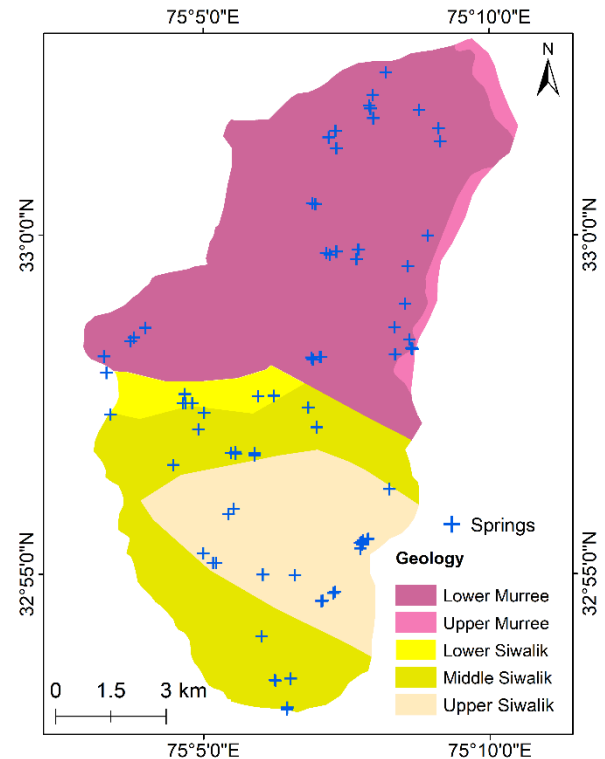


Fig. 8: Distribution of springs in the catchment.

Relationship between lineament characteristics and spring occurrences

As discussed earlier the geological features, which can be represented by lineaments, affect the genesis of springs in a region, an attempt was made to study the spring occurrences vis-à-vis lineaments. Therefore, various characteristics of the lineament i.e., density, length, cross dot (i.e., intersection point of lineaments) were analysed with respect to spring occurrences. Besides, occurrences of spring vis-à-vis lineament proximity were also studied and discussed in the subsequent sections.

Frequency of lineaments and springs occurrences

The lineament density map was prepared in the ArcGIS environment depicting the number of lineament per sq. km area. After creating the lineament density map for the study area, its relation with the occurrence of the springs was investigated. It was found that frequency of lineament has direct relation with the occurrence of the springs. Minimum number of springs occurred in a region where lineament density is one or less than one whereas occurrence of springs increases with the increase in the lineament

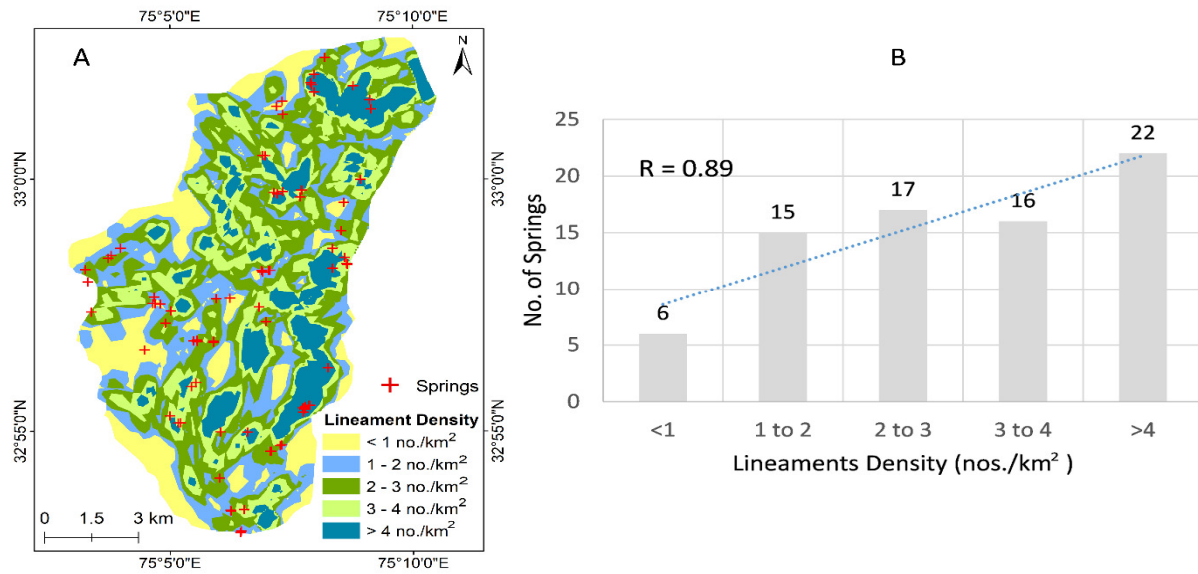


Fig. 9: (A) Lineament Density map (number of lineament divided by area) and (B) lineament density and number of springs.

density (Fig.9A). A strong correlation coefficient ($R = 0.89$) is found between the number of springs and lineament density (Fig. 9B). Such strong value of coefficient of determination indicates that frequency of lineament has a considerable effect on the occurrence of springs.

Lineament length and springs occurrences

The lineament length density was estimated in ArcGIS and to prepare the density map. The lineament length density map was further reclassified into five different classes as shown in the Fig.10A. The maximum and minimum length

of the lineament found in the catchment is 5.33 km and 0.1 km, respectively. The relationship between spring occurrence and the lineament length was investigated and it was found that the length of lineaments and occurrences of springs also have direct relation. Maximum numbers of springs were found in the region where lineaments length is more than 5km/km² (35 springs out of 83 springs). A very strong positive correlation ($R = 0.96$) between the lineament length and spring occurrences infers that lineament length also favours the occurrence of springs (Fig. 10B).

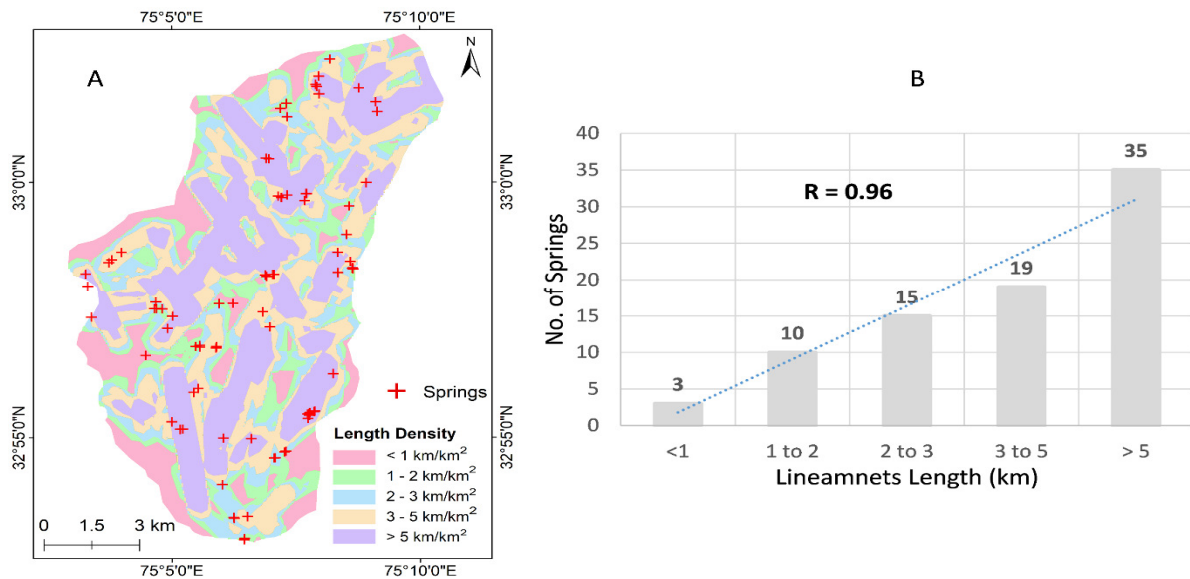


Fig. 10 : (A) Lineament length density map, and (B) lineament length density and number of springs.

Cross dots and springs occurrences

Cross dots are points where two lineaments intersect each other. Density map (dot/km²) of these intersection points was created using 'point density' tool in ArcGIS. Fig.11A shows a density map that is prepared for the cross dots of extracted lineaments in ArcGIS. A high degree of positive correlation ($R = 0.95$) was observed between occurrence of springs and cross dots density as depicted in Fig.11B. It can be seen from Fig. 11B that maximum number of springs occurred in a region where cross dot density is more than 2 dot/sq. km. This clearly indicates that the density of lineament cross dot has a strong influence over the occurrence of springs. A positive correlation substantiates the hypothesis that cross dots i.e. points of intersection of two lineaments can be probable location of springs or can have great control on spring occurrence.

Lineament proximity and spring occurrence

To study the relationship between occurrences of a spring with its proximity to a lineament, distance of nearest lineament to each of the geo-tagged spring was estimated. The distances obtained for a total of 83 geo-tagged springs were divided in the class intervals of 0-50 m, 50-100 m, 100-150 m, 150-200 m and >200 m. Total number of springs falling in each class were analysed to gain insight about spring occurrences vis-a-vis lineament proximity. A strong negative correlation ($R = -0.97$) instances of spring occurrences with respect to their distance to nearest lineament (Fig. 12), which infers that possibility of spring occurrence decreases with increase in distance from the lineaments was found (Fig 12) or there is a strong likelihood of spring occurrence within a close proximity of a lineament. Therefore, most of the water conservation activities should be oriented in the proximity of the lineaments for augmentation of the spring discharge.

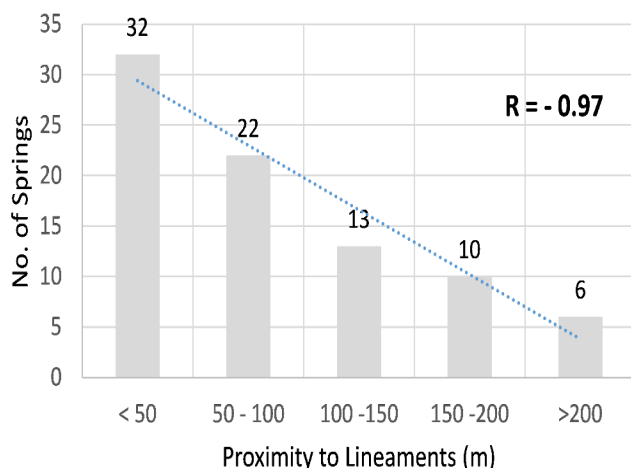


Fig.12 : Proximity to lineaments versus spring occurrences

CONCLUSION

Spring water, a prime natural resource in mountainous region is rapidly deteriorating due to its improper utilization, assessment, and management. The protection and proper management of this natural resource is essential to maintain its quality and quantity especially when its availability is less. Factors responsible for the genesis of springs are crucial to understand for developing an efficient springshed management program across the mountain. Typical geology of the mountain and harsh climatic condition discourage the field investigation to investigate the causes for occurrence of the springs. Huge population of spring and their location disadvantage are the main constraints to study every springs individually. Therefore, in the present study, modern RS and GIS techniques were employed to extract the lineaments from the freely available DEM. Relationship between various characteristics of lineament and the occurrences of the springs were studied. As per the findings of the study, lineament density, length of lineaments, cross dot, and lineament proximity have a significant impact on the occurrence of springs in the study area. It was observed that spring occurred in the proximity of the lineament and most of the springs occurred near the longest lineament. Such relations infer towards the strong control of various intrinsic characteristics of lineament over the occurrence of springs in the area.

Following the findings of the study, it can be suggested that conservation measures should be applied in the proximity of lineaments for augmentation of spring discharge. In addition, such exercises can be immensely useful towards saving of huge time and funds involve in intensive field investigation to identify the recharge zones of the springs. However, it must be noted that user's skill or understanding of study area is vital to optimize different operational parameters to extract the realistic picture of lineaments of the study area.

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