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HYDROLOGIC RESPONSE OF TAKARLA-BALLOWAL WATERSHED IN SHIVALIK FOOT-HILLS BASED ON MORPHOMETRIC ANALYSIS USING REMOTE SENSING AND GIS

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ABSTRACT

Hydrologic response leads to assessment of the potential of water resource in a watershed. Hydrologic response of Takarla-Ballowal watershed, which is located in Shivalik foot-hills of Punjab has been studied based on morphometric analysis using remote sensing and GIS. The total area of the watershed is 2401.82 hac. The slope of around 46.17% of the watershed area is less than 10%; 54.60% and 26.64% areas of the watershed have been categorized as forest land and agricultural land, respectively. The watershed has 6th order stream. Out of the total number of 736 streams identified, 524 are of 1st order. The total stream length is 168.06 km. The drainage pattern is dendritic in nature with stream frequency of 30.72 no./km^2 and mean bifurcation ratio of 3.7. Drainage density of the watershed (7.02 km/km^2) indicates the closeness of spacing of channels with impermeable sub strata. Very fine drainage texture (30.45 no./km) and small length of overland flow (71.23 m) in the watershed indicate generation of high peaked storm hydrograph with short time base, resulting in high soil erosion rate in the watershed. The form factor (0.31), circularity ratio (0.55) and the elongation ratio (0.63) of the watershed indicate that watershed is moderately elongated in shape, associated with medium to high relief, having moderately permeable sub-soil conditions resulting in moderate runoff volume and peak discharge, resulting in high soil erosion causing problem of siltation in the water harvesting structures.

Keywords: *Hydrologic response, Morphometric analysis, Remote sensing, GIS, watershed slope.*

INTRODUCTION

Water resource assessment and development at watershed scale is an important step towards sustainable agriculture in *Shivalik* foot-hills, locally known as *kandi* area. The *Shivalik* foot-hills are a part of the Himalayan mountain chain which continuously runs from Jammu and Kashmir, Himachal Pradesh, Punjab, Haryana and finally end up at Bhabbar tracts of Garhwal and Kumaon in Uttarakhand. Erratic distribution of rainfall, small land holdings, lack of irrigation facilities, heavy biotic pressure on the natural resources, inadequate vegetative cover, heavy soil erosion, landslides, declining soil fertility and frequent crop failures resulting in scarcity of food, fodder and fuel are the characteristics of this region. A large portion of monsoon rainfall (35-40%) goes as runoff in the torrents originating from the *Shivalik* foot-hills (Bhardwaj and Rana 2008). The annual erosion rate in the *Shivalik* foot-hills is more than 80 Mg ha^{-1}year^{-1} and in some watersheds it is as high as 244 Mg ha^{-1}year^{-1} (Singh *et al* 1992, Bhardwaj and Kaushal 2009). The Takarla-Ballowal watershed which is located about 12 km from Balachaur town in *Shivalik* foot-hills of Punjab state has similar hydrologic conditions requiring urgent conservation planning and treatment for water resource development to sustain agriculture. However, assessment of the hydrologic response of watershed is pre-requisite for planning water resources development measures.

The hydrologic response assessment study of the watershed based on morphometric analysis provides the beneficial parameters for the assessment of the ground water potential zones, identification of sites for water harvesting structures, water resource management, runoff and geographic characteristics of the drainage system. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape, dimension of its landforms. The morphometric analysis consists of linear, aerial and relief aspects (Agarwal 1998). The morphological analysis is a significant tool for understanding the topographic situation and hydrological condition of a catchment area. Morphological parameters within certain value range directly indicate the runoff generation and erosion hazard of a watershed. The erosive condition of the watershed directly indicates the loss of land use and land cover in the watershed. Once the erosive condition is known, the watershed can be restored by reducing erosion by adopting suitable treatment measures. Computation of morphological parameters in GIS environment using remote sensing has proved to be less tedious, fast, most updated and accurate and made best spatial representation of topographic situations (Singh *et al* 2013). Remote sensing and GIS techniques are nowadays used for assessing various morphometric parameters of the watershed, as these provide a flexible environment and powerful tools for the manipulation and analysis of spatial information. The automated determination of watershed characteristics using remote sensing and GIS has been shown to be an efficient, accurate and time saving method for planning soil and water conservation treatments at watershed scale.

STUDY AREA

The Takarla-Ballowal watershed which is located in *Shivalik* foot-hills in Shaheed Baghat Singh Nagar district of Punjab state, India as shown in Fig. 1, has been selected as the study area. The study watershed covers an area of about 2401.82 ha lying between 31^0 8’ 28” N to 31^0 4’ 11” N latitude and 76^0 21’ 52” E to 76^0 25’ 17” E longitude. Average annual rainfall in the watershed is about 898.6 mm, out of which 73% occur during monsoon season in July to September. The soils of the study watershed are loamy sand, sandy loam, sand clay loam and sandy in texture, slightly alkaline in reaction and low in organic carbon content.

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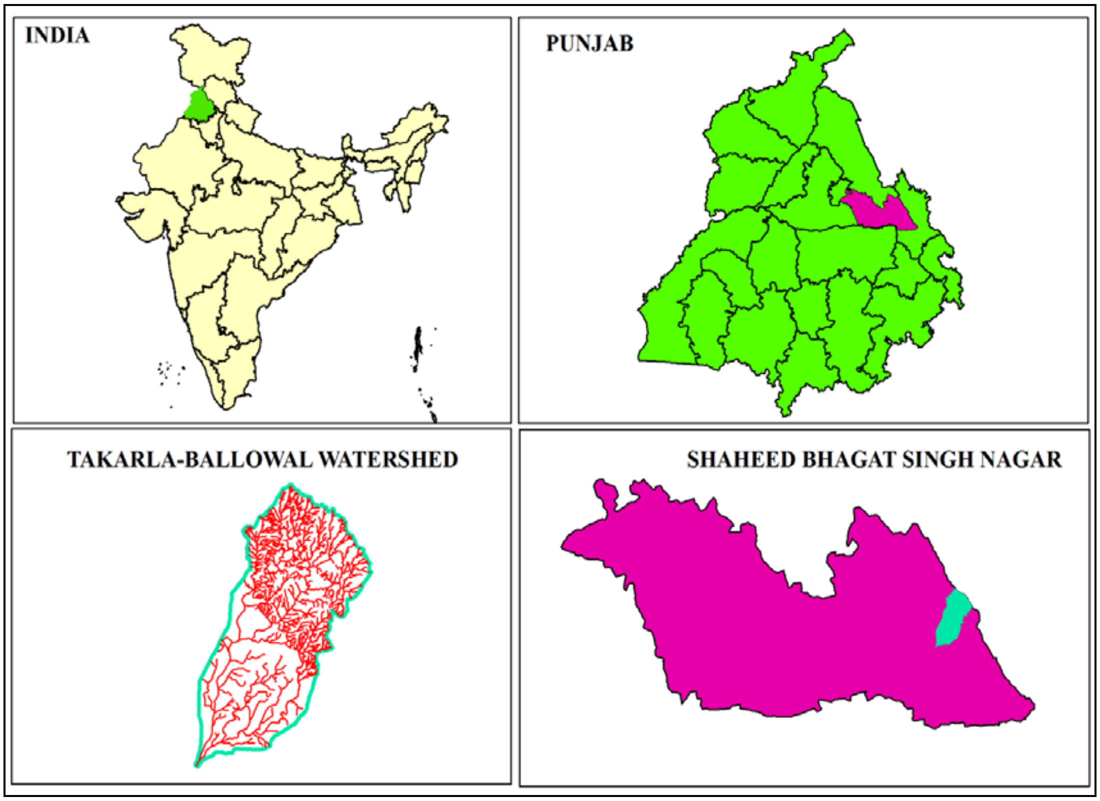

Fig. 1: Location map of the Takarla-Ballowal watershed

MATERIALS AND METHODS

Remote Sensing And GIS Analysis

Topographical Sheet No 53 A/8 on 1:50,000 scale of the Takarla-Ballowal Watershed. (Source: Survey of India), Satellite images of LISS 4 (2009) with spatial resolution of 5.8 m. (Source: PRSC Ludhiana) and ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer) with spatial resolution of 30m were used in the study. The present study utilized digital data of Indian Remote Sensing (IRS) LISS IV of year 2009 having a spatial resolution of 5.8 m. For detailed study, ASTER was used for delineating watershed boundary, slope, flow direction, flow accumulation, aspect and relief. Drainage map was prepared by on screen digitization using ArcGIS 9.3 software. After completion of map generation, field verification or ground truth survey was carried out and final theme maps were prepared. Quantitative morphometric parameters have been calculated in ArcGIS environment for hydrologic response study. The parameters namely: the watershed area, perimeter, watershed length, number of streams and stream length are derived from the drainage layer. The morphometric parameters namely: stream order and stream length, bifurcation ratio, drainage density, drainage frequency, relief ratio, elongation ratio, circularity ratio, compactness coefficient and relief ratio were calculated from the generated maps.

Morphometric Parameters

The morphometric analysis of Takarla-Ballowal watershed has been carried out. The morphometric analysis of a watershed indirectly reflects hydrogeological status of the watershed. The *watershed area* is probably the single most important basin parameter for hydrologic design. It reflects volume of water that can be generated from the rainfall. It is expressed in ‘km^2’. The watershed *perimeter* is the length of the watershed boundary. It is expressed in ‘km’. The streams have been ranked by *stream ordering* system based on hierarchic ranking of streams. In a stream segment, with no tributaries is designated as a first-order stream, a second-order stream is formed by joining of two first-order streams, where two second-order streams join, the stream is designated as third-order, and so forth (Strahler 1957). It is expressed as ‘U_n’.

Bifurcation ratio is a dimensionless parameter that expresses the ratio of the number of streams of any given order (N_u) to the number of streams in the next higher order (N_{u+1}) (Schumn 1956) and is calculated as:

$$R_b = N_u / N_{u+1} \quad (1)$$

Length of overland flow has been calculated as per Horton (1945). It is defined as the length of water over the ground before it gets concentrated into definite stream channel. The average length of overland flow is approximately half the average distance between stream channels and is therefore approximately equals to half of reciprocal of drainage density, expressed as:

$$L_o \text{ (km)} = 1/ D_d \times 2 \quad (2)$$

Where, D_d = Drainage density (km/km^2).

Drainage density has been calculated as the cumulative length of all streams in a watershed divided by the area of the watershed (Strahler 1957). It is expressed in ‘km/km^2’ and is given by:

$$D_d = (\Sigma L_u)/A_u \quad (3)$$

Where, L_u=Total Stream length of all orders (km), A_u= Area of the watershed (km^2).

Drainage texture has been calculated as the total number of stream segments of all orders divided by the perimeter of the watershed (Horton 1945). It is expressed in 'no./km'.

$$T = \Sigma N_u/P \qquad (4)$$

Where, N_u= Total number of streams in the watershed, P = Watershed perimeter (km).

Stream frequency has been calculated as per definition given by Horton (1932) as the ratio of total number of stream segments of all orders to the watershed area. It is expressed in 'no./km^2' and calculated as:

$$F_s = \Sigma N_u / A_u \qquad (5)$$

Where, N_u=Total number of streams in the watershed, A_u= Area of the watershed (km^2).

Form factor may be defined as the ratio of the area of the watershed to the square of watershed length (Horton 1932). It is the quantitative expression of watershed outline form, estimated as:

$$R_f = A_u / L_b^2 \qquad (6)$$

Where, L_b= Maximum watershed length, A_u= Area of the watershed (km^2).

The *circularity ratio* has been calculated as the ratio of the area of the watershed to the area of a circle having the same circumference as the perimeter of the watershed (Miller 1953) and is given by:

$$R_c = 4\pi A_u / P^2 \qquad (7)$$

Where, A_u = Area of the watershed (km^2), P = Perimeter of the watershed (km).

The *Elongation ratio* has been calculated as per Schumm (1956). It is defined as the ratio of diameter of a circle of the same area as the watershed and the maximum length of the watershed.

$$R_e = \sqrt{(4A_u/\pi)} / L_b \qquad (8)$$

Where, A_u = Area of the watershed (km^2), L_b= Maximum watershed length (km).

Compactness coefficient is defined as the ratio between the area of the basin and the perimeter of the basin (Horton 1945). It is calculated by the equation:

$$C_c = 0.2821P / A_u^{0.5} \qquad (9)$$

Where, P = Perimeter of the watershed (km), A_u= Area of the watershed (km^2).

The *relief ratio* may be defined as the ratio between the total relief of a watershed and the longest dimension of the watershed parallel to the main drainage line (Schumm 1956). There is a direct relationship between the relief and gradient of the channel. It is given by:

$$R_h = H / L_b \text{ max} \qquad (10)$$

Where, H = Maximum watershed relief (km), L_b max = Maximum watershed length (km).

Table 1: Morphometric parameters of the Takarla-Ballowal watershed

S. No.	Parameter	Value
1	Watershed area (ha)	2401.82
2	Perimeter (km)	24.17
3	Length of watershed (km)	8.76
4	Total length of stream (km)	168.06
5	Total number of streams	736
6	Bifurcation Ratio	3.7
7	Length of overland flow (m)	71.3
8	Drainage density (km/km^2)	7.02
9	Drainage texture (no./km)	30.45
10	Stream frequency (no./km^2)	30.72
11	Form factor	0.31
12	Circularity ratio	0.52
13	Elongation ratio	0.63
14	Compactness coefficient	1.39
15	Relief ratio	0.024

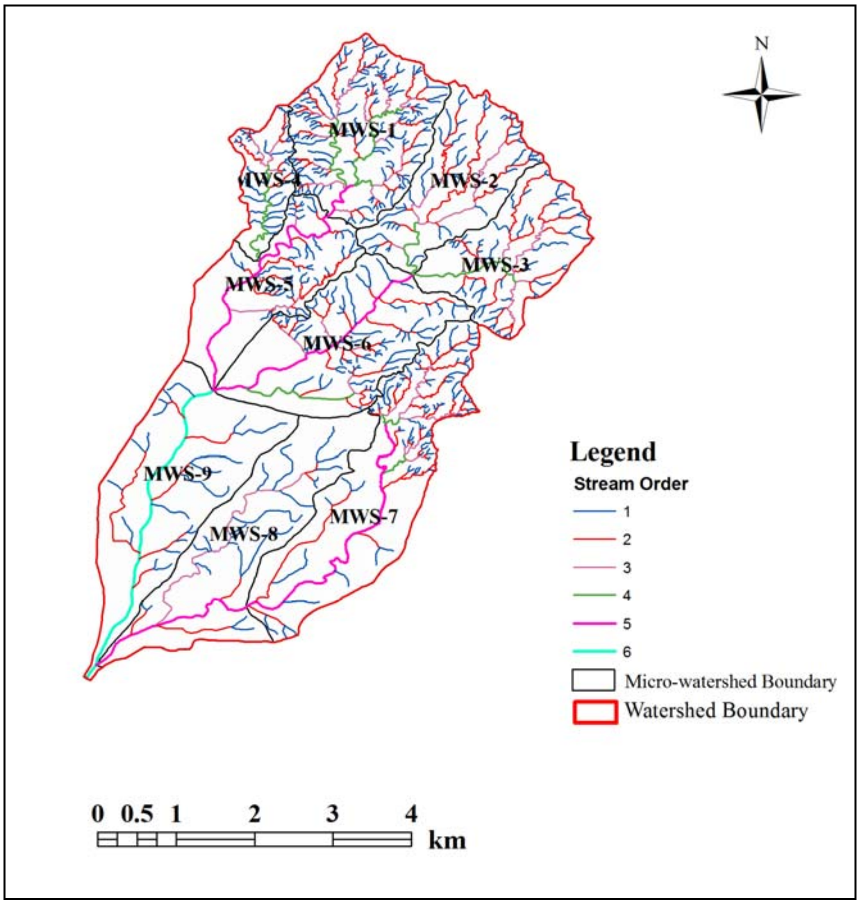

Fig. 2: Drainage and stream order map of Takarla-Ballowal watershed

RESULTS AND DISCUSSION

Basic Watershed Parameters

Watershed area is hydrologically important because it directly affects the base of the storm hydrograph, magnitude of peak and the total runoff which is available at the watershed outlet for harvesting. The area of Takarla-Ballowal watershed was found to be 2401.82 ha, having perimeter of 24.17 km. The watershed length (L_b), as defined by Horton (1932) as the straight-line distance from watershed outlet to the point on the watershed divide intersected by the projection of the direction of the line through the main stream is 8.76 km (Table 1).

Morphometric Analysis And Hydrologic Response

Morphometric analysis is a significant tool for hydrologic characterization of a watershed even without considering the soil map. The different morphometric parameters calculated for Takarla-Ballowal watershed have been presented in Table 1 and discussed.

Linear Aspects

Stream order (U_n): The drainage and stream order map of Takarla-Ballowal watershed is shown in Fig. 2. The Takarla-Ballowal watershed is a 6th order drainage basin. The total number of 736 streams are identified of which 524 are 1st order streams, 153 are 2nd order, 52 are 3rd order, 10 in 4th order, 3 are 5th order and 1 is 6th order stream. There is a inverse relationship between number of stream (N_s) and the order of the streams (U_n) in the watershed (Fig. 3). High value of r (0.928) indicates good correlation between these two parameters. The relationship is represented by the following regression equation:

$$N_s = -287 \ln U_n + 437.3 \quad (11)$$

Where, N_s is the number of streams of the order U_n, n = 1, 2, 3 ------- 6.

Stream length (L_u): In the study watershed, total length of stream segments is maximum for first order and decreases as stream order increases, as shown in Fig. 4 and Table 2. The stream length of 1st order is maximum (149.5 km) and minimum (7.38 km) for 6th order. Streams of relatively smaller lengths indicate high slope and finer texture there by will generate more runoff. There is a good relationship between stream length and stream order in watersheds as indicates by high correlation coefficient (0.979). The overall relationship

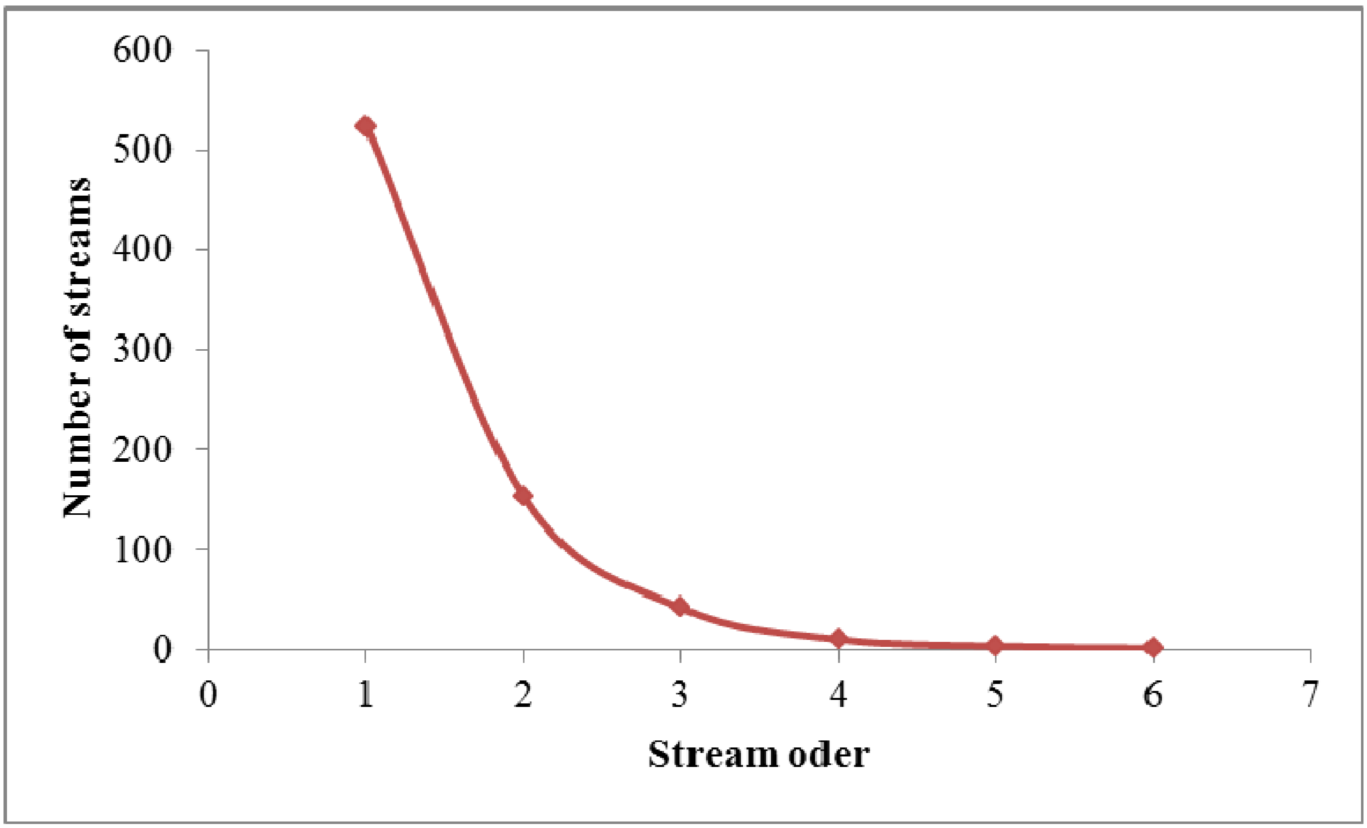

Fig. 3: Variation of number of stream with stream order in Takarla-Balowal watershed

Table 2: Number of streams and stream length of different order streams in Takarla-Ballowal watershed

Stream order	Number of streams	Stream length (km)
1st	524	74.75
2nd	153	44.71
3rd	42	21.12
4th	10	13.26
5th	3	10.01
6th	1	4.19

for Takarla-Ballowal watershed is represented by the following equation:

$L_u = -39.7 \ln U_n + 71.63$ (12)

Where, L_u is the length of streams (km) of the order U_n, n = 1, 2, 3 ------- 6.

quick concentration of runoff resulting in high water yield.

Drainage texture (T): The drainage texture of Takarla-Ballowal watershed is 30.45 no./km. Drainage texture provides information on the relative spacing of drainage lines. Drainage texture is affected by natural factors such as climate, rainfall, vegetation, rock and soil type, relief and stage of development of a watershed. Smith (1954) classified drainage texture, i.e. < 2 indicates very coarse, between 2 and 4 is coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage texture. Hence, the drainage texture of Takarla-Ballowal watershed is fine drainage texture. It indicate good availability of runoff water for harvesting in the watershed.

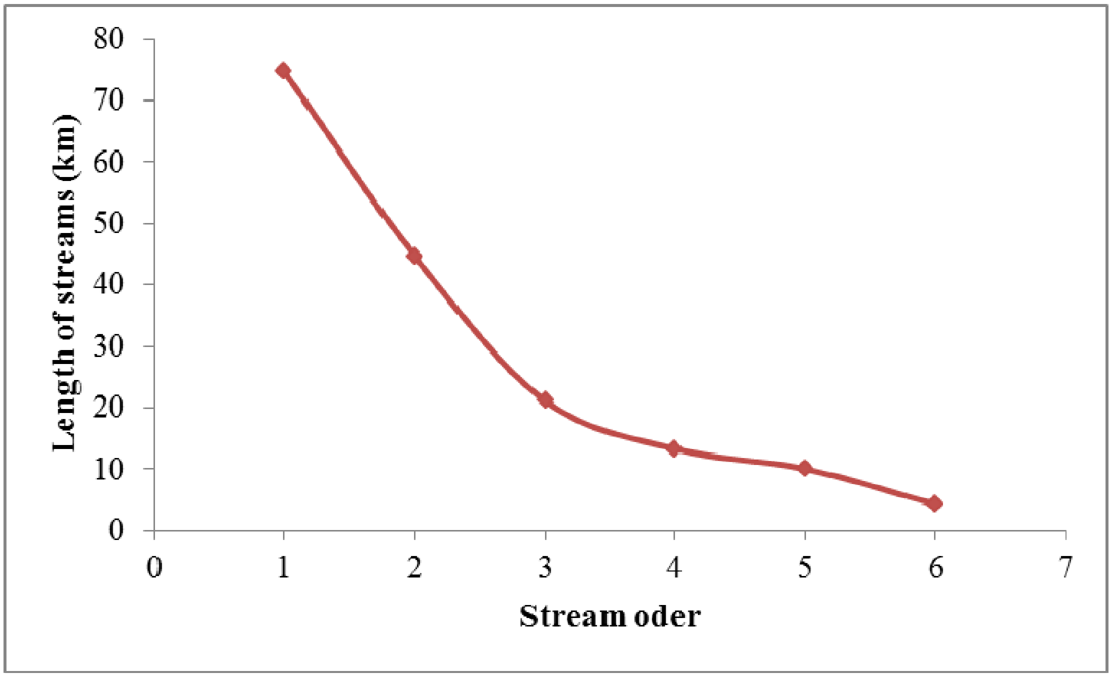

Fig. 4: Variation of stream length with stream order in Takarla-Balowal watershed

Bifurcation ratio (R_b): The bifurcation ratio ranged from 3.0 to 4.2 in the watershed which indicates that the geologic structures do not distort the drainage pattern. Higher values of Bifurcation ratio indicate strong structural control in drainage pattern while the lower values are indicative of not affected by structural disturbances (Dwivedi, 2011). The mean bifurcation ratio is 3.7 for the Takarla-Ballowal watershed, which indicates that geological structures are less disturbing the drainage pattern. Also, the watershed is less elongated and may result in high peak of runoff rate (Strahler 1964).

Length of Overland Flow (L_o): The computed value of the length of overland flow for Takarla-Ballowal watershed is 71.3 m. The value is less than the standard length of around 100 meters. It means that it has the potential to cause sheet erosion owing to the shorter overland flow distance and quicker runoff concentration.

Aerial Aspects

Drainage density (D_d): The drainage density indicates the closeness of spacing of channels. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture. The drainage density of Takarla-Ballowal watershed is 7.02 km/km^2, which is quite high indicating impermeable sub surface materials, sparse vegetation and mountainous relief resulting in high runoff and soil erosion (Strahler, 1964). However, magnitude of soil erosion would depend upon the development stages of the drainage lines in the watershed. In general there would be

Stream frequency (F_s): Stream frequency or channel frequency is directly related to stream population per unit area of the watershed (Horton 1932). It indicates the close correlation with drainage density value of the micro-watershed. The stream frequency of the Takarla-Ballowal watershed is 30.72 no./km^2. Higher value of stream frequency indicates that the topography of the watershed is not plain and less amount of rainfall would infiltrate into the soil, resulting in higher generation of runoff.

Form factor (R_f): The value of form factor less than 0.7854 indicates a perfectly circular basin (Horton 1932). The form factor is equal to unity when the basin shape is a square, and decreases according to the extent of elongation. Smaller value of the form factor indicates maximum elongation of the watershed. The value of form factor of Takarla-Ballowal watershed is 0.31, which indicate that the watershed is slightly elongated in shape. This type of watershed with sloping topography results in moderate to high runoff generation.

Circularity ratio (R_c): Circularity ratio is influenced by the length and frequency of streams, geological structures, land use/ land cover, climate, relief and slope of the watershed. In the Takarla-Ballowal watershed, the circulatory ratio value is 0.55, indicating that the watershed is moderately elongated in shape having moderate discharge of runoff and moderate permeability of sub soil conditions. Such drainage systems are partially controlled by the structural disturbances causing problem of soil erosion in the uplands and siltation in downstream water harvesting structures to some extent.

Elongation ratio (R_e): Generally, the values of elongation ratio (R_e) lie between 0.6 and 1.0 which is associated with a wide variety of climate and geological properties. The values close to 1.0 are typical of regions of very low relief, whereas that of 0.6 to 0.8 are followed with high relief and steep ground slope (Strahler 1964). These values can be grouped into three categories, namely circular (0.9), oval (0.9-0.8) and less elongated (0.7). The elongation ratio of Takarla-Ballowal watershed is 0.63 which indicates that watershed is less elongated in shape resulting into generation of moderate quantities of runoff.

Compactness coefficient (C_c): Compactness coefficient is inversely proportional to the erosion risk assessment. Higher value signifies less vulnerability for risk factors, while lower value indicates great vulnerability and represents the need of implementation of conservation measures. The value of compactness coefficient for Takarla-Ballowal watershed is 1.39.

Relief Aspect

Relief ratio (R_h): The value of relief ratio is 0.024 in the Takarla-Ballowal watershed, which is moderately low. In general, the value of relief ratio in upper part of watershed is high which indicates steep slope of watershed resulting into generation of high volume of runoff.

Table 3: Area under different slope ranges with in Takarla-Ballowal watershed

S. No	Slope Range (%)	Area (ha)	Area (%)	Cumulative percent area
1	< 5	538.73	22.43	22.43
2	5-10	570.19	23.74	46.17
3	10-15	378.77	15.77	61.94
4	15-20	273.81	11.4	73.34
5	20-25	212.08	8.83	82.17
6	25-35	162.84	6.78	88.95
7	35-45	122.49	5.1	94.05
8	45-65	79.01	3.29	97.34
9	65-100	43.71	1.82	99.16
10	> 100	20.17	0.84	100
Total		**2401.82**	**100**	

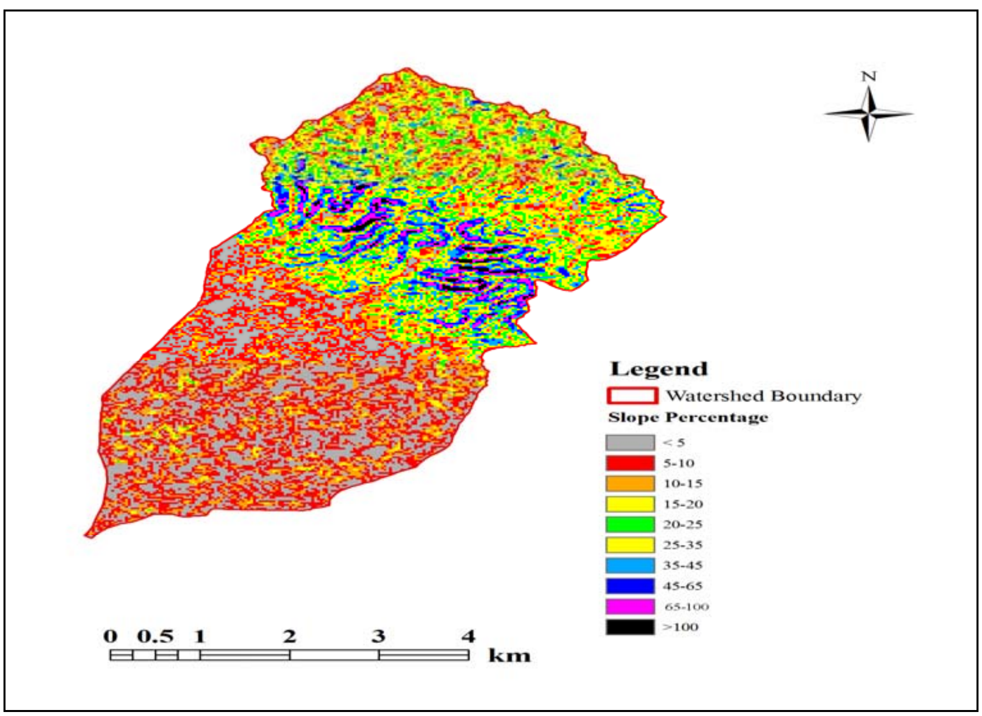

Fig. 5: Slope map of Takarla-Ballowal watershed

Slope Of Watershed

Slope of the watershed is vital for making land capability assessment and in the estimation of runoff and soil loss. The slope map of the Takarla-Ballowal watershed has been shown in Fig. 5. The slope in the watershed is classified into ten slope classes (Table 3). Around 53.83 % of the watershed area is having slope greater than 10% and that some of the areas within the watershed are having slope as high as 100%. The runoff generation from these areas would be quite high and there is good scope of constructing water harvesting structures in this area and utilizing the harvested runoff water in the downstream agricultural area.

Land Use

The land use map of the Takarla-Ballowal watershed for the year 2009 is shown in Fig. 6. Forest, agricultural land, fallow land, land with scrub, land without scrub, plantation and

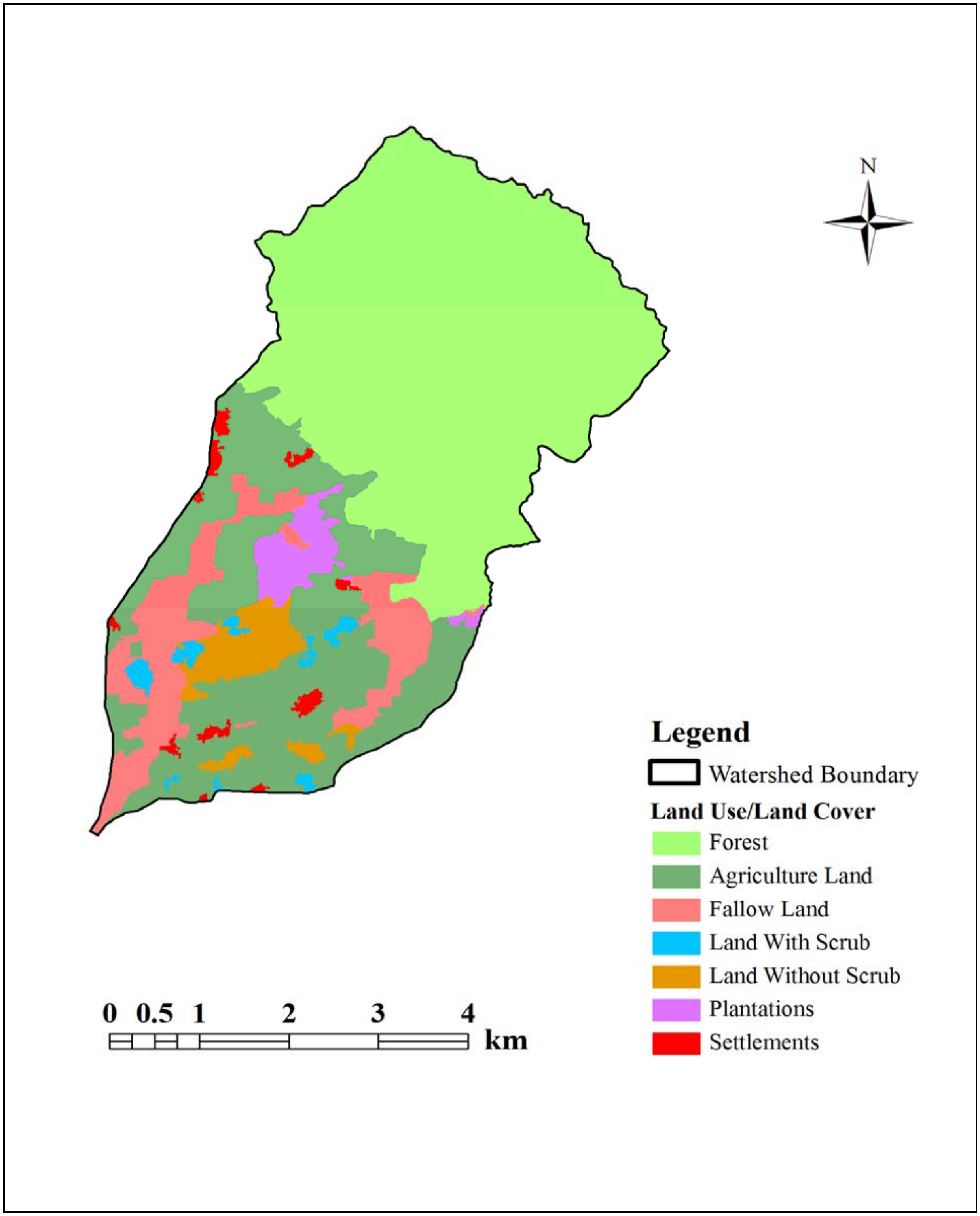

Fig. 6: Land use map of Takarla-Ballowal watershed

settlement were identified as major land use system categories in the watershed. The percent area under different land uses has been depicted in the form of a pie chart in Fig.7. Major portion of the land in Takarla-Ballowal watershed is under forest (54.6%) followed by agricultural land (26.64%). Forests are located on the upland areas where land slope is high and agricultural land is located in the area where the topography is comparatively plain. The area under settlement is only 1.19% of the total area of the watershed. The prevailing land use of the watershed indicates generation of moderate quantities of runoff due to higher degree of slope in forest land. The aerial parameters namely, form factor (0.31), circularity ratio (0.50) and elongation ratio (0.63) indicate that watershed is moderately elongated in shape, having moderate sub-soil permeability

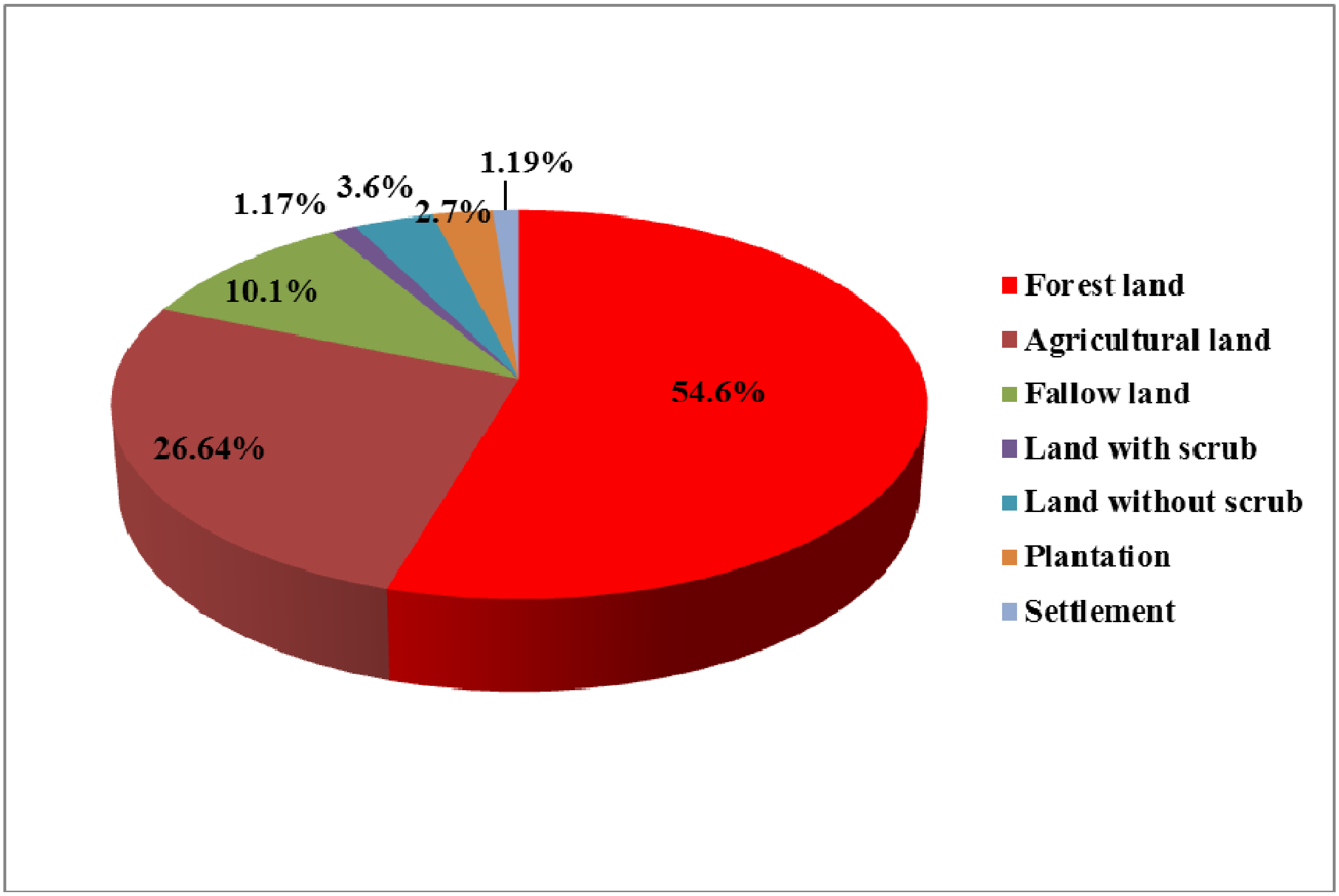

Fig. 7: Pie chart of the percent area under different land uses in the Takarla-Ballowal watershed

CONCLUSIONS

The extent of water resource development would depend on the hydrologic response of the watershed. In this study hydrologic response of the Takarla-Ballowal watershed has been studied based on morphometric analysis of the watershed using remote sensing and GIS. The drainage density of the Takarla-Ballowal watershed (7.02 km/km^2) indicates the closeness of spacing of channels with impermeable sub strata; the drainage texture (30.45 no./km) categorise the watershed as fine drainage texture, and small length of overland flow (71.23m) indicate generation of high peaked storm hydrographs with short time base, resulting in moderate quantity of runoff generation, but high soil erosion rates in the watershed. The slope of around 46.17% of the watershed area is less than 10%; 54.60% and 26.64% areas of the watershed have been categorized as forest land and agricultural land, respectively. The runoff potential of the watershed seems to be moderate with possibilities of high siltation rates in the downstream water harvesting structures necessitating conservation treatment planning in these catchments for sustainable water resource development in the watershed. The study also demonstrates the usefulness of Remote Sensing and GIS in morphometric analysis for hydrologic response studies at watershed scale.

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