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Geomorphological Analysis and Hydrological Potential Zone of Baira River Watershed, Churah in Chamba District of Himachal Pradesh, India

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A B S T R A C T

In the present study, an attempt has been made to study the quantitative geomorphological analysis and hydrological characterization of 95 micro-watersheds (MWS) of Baira river watershed in Himachal Pradesh, India with an area of 425.25 Km^2. First time in the world, total 173 morphometric parameters have been generated in a single watershed using satellite remote sensing data (*i.e.* IRS-P6 ResourceSAT-1 LISS-III, LandSAT-7 ETM+, and LandSAT-8 PAN & OLI merge data), digital elevation models (*i.e.* IRS-P5 CartoSAT-1 DEM, ASTER DEM data), and soI topographical maps of 1: 50,000 scale. The ninety-five micro-watersheds (MWS) of Baira river watershed have been prioritized through the morphometric analysis of different morphometric parameters (*i.e.* drainage network, basin geometry, drainage texture analysis, and relief characterizes). The study has concurrently established the importance of geomorphometry as well as the utility of remote sensing and GIS technology for hydrological characterization of the watershed and there for better resource and environmental managements.

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1. INTRODUCTION

Geomorphometry is the science ''which treats the geometry of the landscape", and quantitative procedure of the land surface.(Chorley *et al.*, 1957) Morphometry is the quantitative analysis of the conformation of the earth's surface, shape and dimension of its landforms. The field of geomorphology fundamentally characterizes the topographical appearance of land by way of area, slope, shape, length, *etc.* A major highlighting in geomorphology over the past several decades has been on the development of quantitative physiographic methods to describe the evolution and behavior of surface drainage networks (Horton, 1945; Abrahams, 1984).

Some quantitative approaches have been documented to identify the basin drainage characteristics, and for sympathetic of various hydrological processes. The morphometric characteristics at the watershed scale may contain important information regarding its formation development and spatio-temporal variations because all hydrologic and geomorphic processes occur within the watershed. The quantitative measurement of landforms has become the current trust of geomorphology. Earlier, it has been well attempted by various hydrologists, geologists and geomorphologists. (Horton, 1932; Horton, 1945; Potter, 1957; Schumm, 1956; Mueller, 1968; Sutherland & Bryan, 1991; Rahmat & Mutolib, 2016) Morphometry is potentially a most important approach to geomorphology, since it affords quantitative information on large scale fluvial landforms, which make up the vast majority of earth configuration.

Micro-watershed is the fundamental unit in hydrology; consequently, geomorphometric analysis at micro-watershed scale is helpful and better rather carries it out on completes it on particular channel or inconsistent segment areas. Hydrologic and geomorphic strategies happen contained by the watershed, and morphometric characterization at the watershed scale reveals data considering formation and improvement of land exterior methods (Dar *et al.*, 2013) and thusly is responsible of a comprehensive comprehension into the hydrologic behaviour of a watershed. Additionally, some of the morphometric parameters, for example, circularity proportion and bifurcation ratio are input parameters in the hydrograph examination (Jain *et al.*, 2000; Angillieri, 2008) and assessment of surface water capability of an area (Suresh *et al.*, 2004). In this point of view, this study covers a better thoughtful of hydrologic conduct of the study area and the geomorphometric analysis of micro-watersheds (MWS) for hydrological scenario evaluation and characterization Baira river watershed, Churah in Chamba district of Himachal Pradesh, India.

2. MATERIALS AND METHODS

In the present study, an attempt has been made to study the quantitative geomorphological analysis and hydrological characterization of 95 micro-watersheds (MWS) of Baira river watershed in Himachal Pradesh, India with an area of 425.25 km^2. First time in the world total 173 morphometric parameters have been generated in a single watershed by using satellite remote sensing data *i.e.* IRS-P6 ResourceSAT-1 LISS-III, LandSAT-7 ETM$^+$ and LandSAT-8 PAN & OLI merge data, digital elevation models *i.e.* IRS-P5 CartoSAT-1 DEM, ASTER DEM data, and SoI topographical maps of 1: 50,000 scale.

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3. RESULTS AND DISCUSSION

3.1. STUDY AREA

The watershed area of Baira River is 425.25 kms^2 & located between 32.85 N to 33.02 N latitude and 76.02 E to 76.38 E longitudes (see **Figure 1**). The river Baira originates from the Sach Pass of Churah tehsil of Chamba district at a height of 5268 m, flows towards south, south-east and finally joins the river Makkan at Buin village of Chaurah tehsil of Chamba district in Himachal Pradesh. Baira river is 19.07 Kms long, however there is only one main tributaries of the right bank of Baira river *i.e.* Malin Nadi, there are some major tributaries pouring into the left bank river, notable amongst there are Cheni Nala, Trishan Nala, Tabriyali Nala, Bhusandu Nala and Chhawed Nala. The study area falls in Survey of India (1:50,000) toposheets No. 52C/04 (I 3Q/04), 52 /08 (I43Q/08), 52D/01 (I43W/01) and 52D/05 (I43W/05). According to new watershed codification system (Pareta & Pareta, 2014), total 95 micro-watershed (MWS) has covered the whole study area.

3.2. DATA USED, SOURCES AND METHODOLOGY

Different type of data has been used for this study. Data from satellite remote sensing are: LandSAT-7 ETM$^+$, ResourceSAT-1 LISS-III, and LandSAT-8 OLI & PAN, ASTER (DEM), CartoSAT-1 (DEM), and other ancillary data *i.e.* Survey of India (SoI) topographical map at 1: 50,000 scale and geological map (GSI) have been collected from concern agency. The details of different data layers along with its sources and methodology are given in **Table 1.**

Tabel 1. Data used, sources, and methodology

S. No.	Data Layer / Maps	Source / Methodology
1.	Topographical Map	- Topographical map, Survey of India (1: 50,000) - Toposheet No.: 52C/04 (I43Q/04), 52C/08 (I43Q/08), 52D/01 (I43W/01) and 52D/05 (I43W/05).
2.	Remote Sensing Data	- LandSAT-7 ETM$^+$ satellite imagery with 30.0 m spatial resolution: 02nd December, 1999. - IRS-P6 (ResourceSAT-1) LISS-III satellite imagery with 23.5 m spatial resolution: 16th April, 2010. - LandSAT-8 OLI & PAN merge satellite imagery with 15m spatial resolution: 15th March, 2016.
3.	DEM / Elevation Data	- ASTER Global Digital Elevation Model (GDEM), DEM data with 30m spatial resolution: 02nd December, 2007. - CartoSAT-1 Digital Elevation Model (CartoDEM) data with 30m spatial resolution: 26th September, 2010.
4.	Geological Map	- Geological map of Chamba district has been collected from Geological Survey of India (GSI) and updated through ETM$^+$, LISS-III and OLI & PAN merge satellite remote sensing data with limited field check.
5.	Geomorphological Map	- Geomorphological map along with geological structures have been prepared using satellite remote sensing data, CartoSAT-1 DEM / ASTER-DEM and other ancillary data *i.e.* SoI topographical map, GSI geological map with limited field check.
6.	Morphometric Analysis	- Morphometric analysis has been completed based on data created from SoI toposheets / CartoSAT-1 & ASTER (DEM) and different morphometric parameters have been generated by using ArcGIS-10.3 software.

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3.3. WATERSHED CODIFICATION SYSTEM

For this study, authors have been used the watershed codification system proposed by the (Pareta & Pareta, 2014). They have classified entire rivers in India as "2" Indian sub-continent largest transboundary watersheds, "3" water divisions, "6" water sub-divisions, "22" basins, "72" sub-basins, "814" watersheds and then micro classification as sub-watersheds, micro-watershed (MSW), mini-watershed (Mini-WS).

According to them, the study area watershed is situated in the international channel. The water division's code is "A" all drainage flowing into Arabian sea (A), "AS11" Indus river; water sub-divisions code is "A1" all drainage flowing into Arabian sea from north India; basin code is "Id" for Indus river; sub-basin code is "RVI" for Ravi river. They have classified the entire Ravi sub-basin into "8" major watersheds *i.e.* AS11A1Id(RVI)1 to AS11A1Id(RVI)8. They study area is located in the major watershed of AS11A1Id(RVI)7. This watershed future has classified into "12" sub-watersheds and symbolized as AS11A1Id(RVI)7a to AS11A1Id(RVI)7l. Authors have selected 3 sub-watersheds namely AS11A1Id(RVI)7d, AS11A1Id(RVI)7e and AS11A1Id(RVI)7f for this study. Under the above stated sub-watersheds total "95" micro-watershed has been identified and shown in Fig. 2. The completed code for a micro-watershed with eight digits is represented as "AS11A1Id(RVI)7f3", as an example of a micro-watershed of Ravi sub-basin, where "AS11" represents Indian Sub-Continent Largest Transboundary, "A" for Water Division, "1" for Water Sub-Division, "Id" for Basin, "RVI" for Sub-Basin, "7" for Watershed, "f" for Sub-Watershed, and "3" for Micro-Watershed.

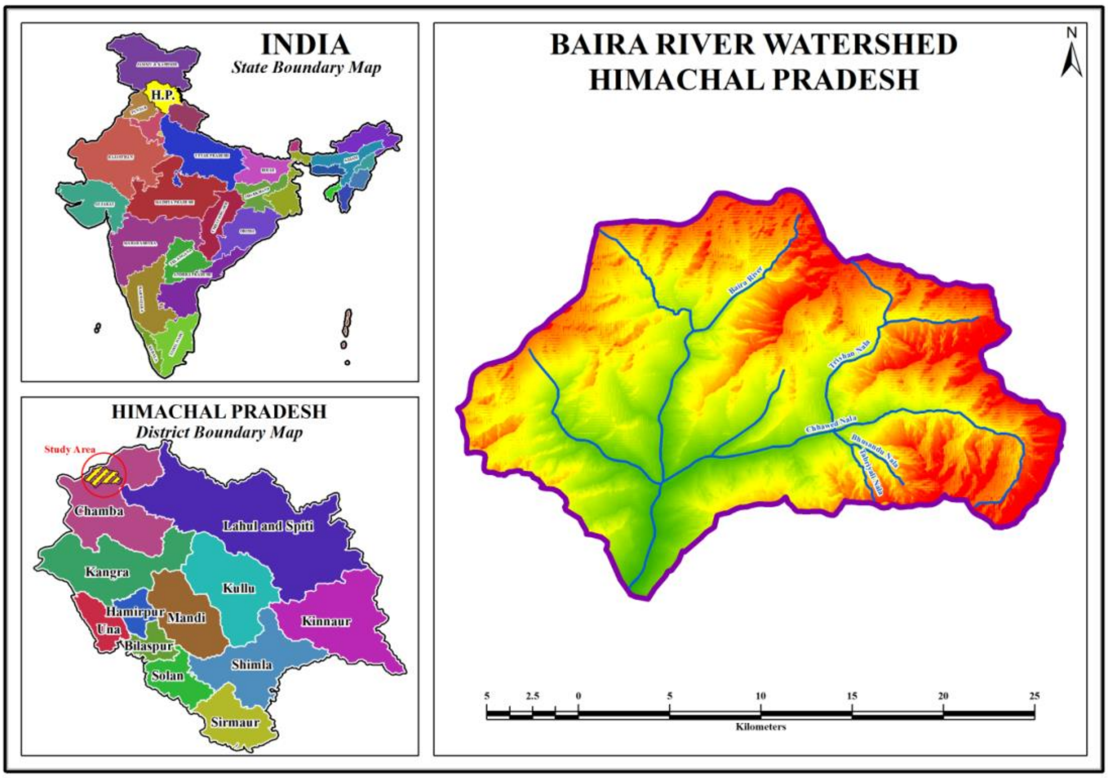

Figure 1. Location map of the study area

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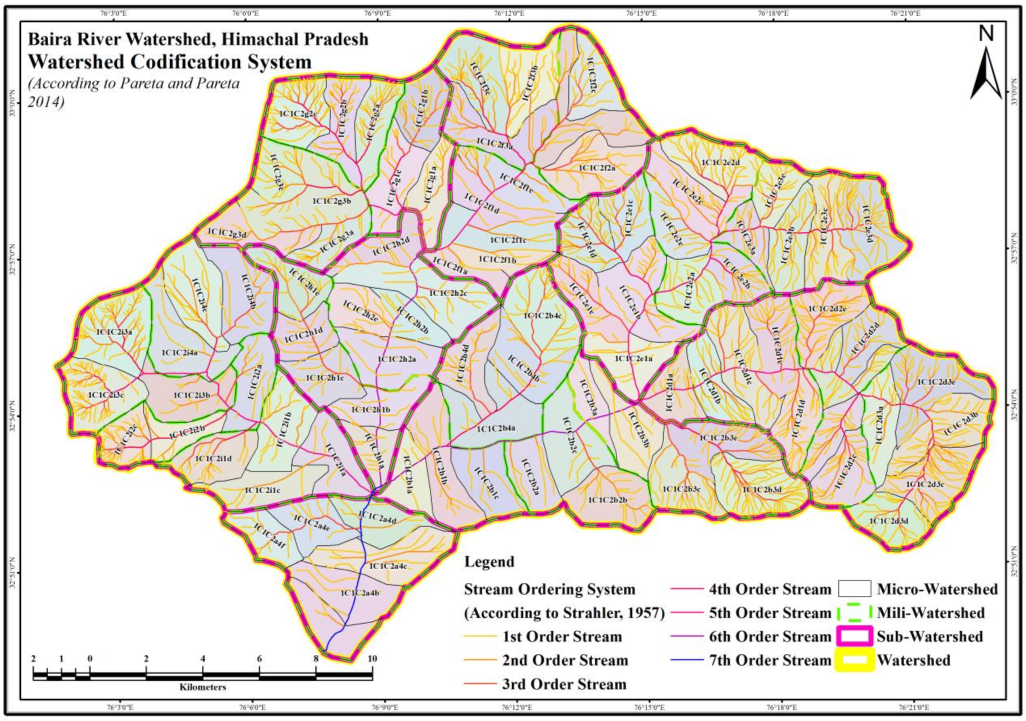

Figure 2. Watershed codification system of baira river watershed

3.4. GEOLOGY

A systematic geomorphic study has been attempted for the terrain classification and their significance with the aid of satellite imagery, digital terrain model and surface characters in the study area. Presently, the knowledge of the geomorphology of the region is very sketchy and hence an appraisal of terrain types, drainage basin, river valleys and the morphometric study to understand the history of geomorphic evolution in this part of the Himalayan belt has been brought out to assist in the study basin management. The gamut of geomorphic description of study area in the region initially dictates the need for understanding the geologic events reflecting the relief and hence the paper highlights first the rock description along with their influence on basin management.

Various folks are studies the geological aspects of the study area (Tomlinson, 1925; De Terra, 1939; Krishnan & Aiyengar, 1940; Woodroffe, 1981; Boison & Patton, 1985). They have recorded the primary rock formations namely (i) Chamba Formation: Slate, Phyllite Carbonaceous Slate and Quartzite; (ii) Katarigali Formation: Dark Grey Slate, Micaceous Sandstone and Quartzite; and (iii) Manjir Formation: Slate, Shale, Sandstone and Limestone. The mountain blocks in the study area are composed of a series of differing architectural elements represented by sedimentary, metamorphosed sediments and igneous massifs in the following tectonic sequence. The study area lies between the two high mountain ranges, *i.e.* the Dhauladhar Range in the southwest and the Zanskar Range or the Great Himalayan Range in the northwest. Stratigraphic sequence of the study area is shown in **Table 2.**

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Tabel 2. Stratigraphic sequence of baira river watershed, himachal pradesh

Age	Group	Formation	Lithology
Neoproterozoic	-	Katarigali	Dark Grey Slate, Micaceous Sandstone and Quartzite
		Manjir	Slate, Shale, Sandstone and Limestone
Undifferentiated Proterozoic	Vaikrita	Chamba	Slate, Phyllite Carbonaceous Slate and Quartzite

Source: Geological Survey of India (GSI)

3.5. METHOD FOR GEOLOGICAL MAPPING

The methods adopted for this research work is divided into two aspects namely field and lab operations. The field operation is essentially geologic mapping of the study area to determine the underlying lithologic units. The geologic mapping was carried out at a scale of 1:50,000 using grid-controlled sampling method at a sampling density of one sample per 9 km^2 for the collection of stream sediments and rock samples. The location map of field data collection is shown in **Figure 3**. Total fourty-three (43) rock and stream sediment samples were obtained. The rock samples were collected from different localities in the studied area, after which they were labelled accordingly to avoid mix up. The geographical location of each outcrop was determined with the aid of a Global Positioning Systems (GPS) and the lithologic and field description and features characteristic of each sample were correctly recorded in the field notebook. Six distinct lithological units were recognized in the studied area which were compiled to produce a geological map, which are the slate, micaceous sandstone, quartzite, shale, phyllite carbonaceous slate and limestone. The major structure in the area is an anticline, syncline, fault, fractures, joints and lineaments, which are visible on the lithology in the studied area.

For lab operations, a published geological map from Geological Survey of India (GSI) has been used for preparation of geological map of the study area. This geological map has been update through the satellite remote sensing data *i.e.* LandSAT-7 ETM^+, (30m) IRS-P6 (ResourceSAT-1) LISS-III (23.5), LandSAT-8 OLI & PAN merge (15m), CartoSAT-1 (DEM) data (30m), ASTER (DEM) data (30m) by using ESRI based ArcGIS-10.3 software along with comprehensive field work as described above. Other ancillary data like Survey of India (SoI) topographical map at 1:50,000 scales has also used. The above stated data has been used for identification of various geological parameters and lithology of the study area. The detailed geological map of the study area is shown in **Figure. 4**.

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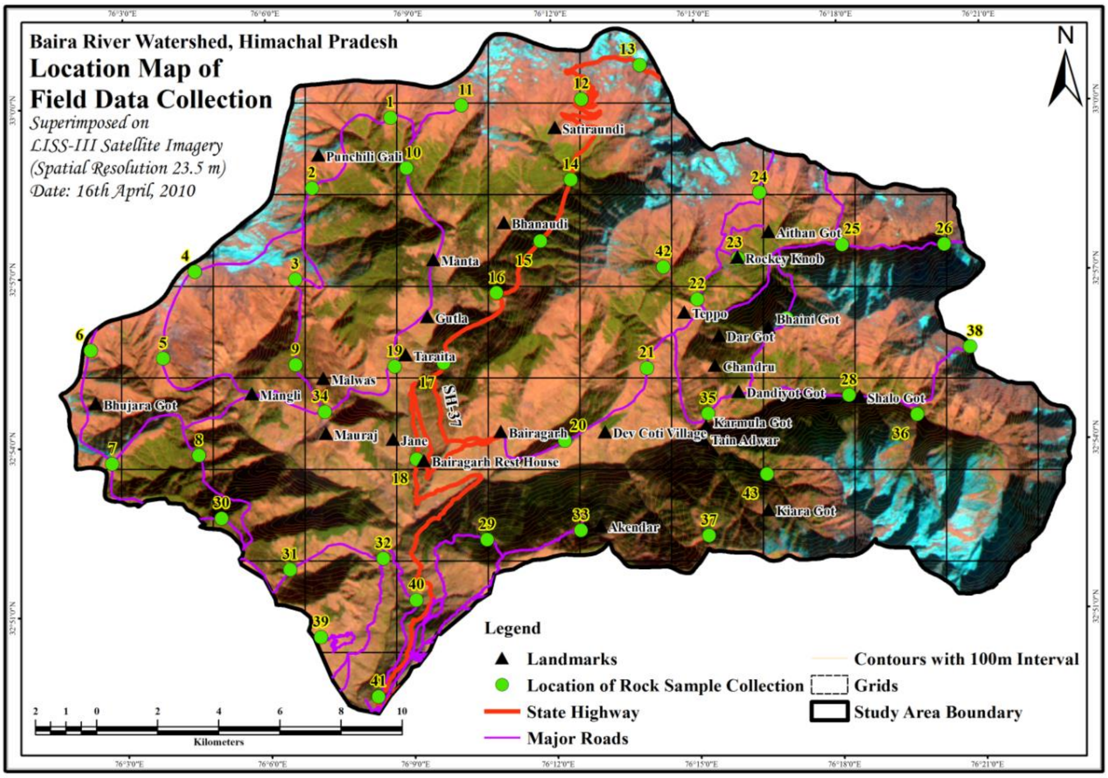

Figure 3. Location map of field data collection

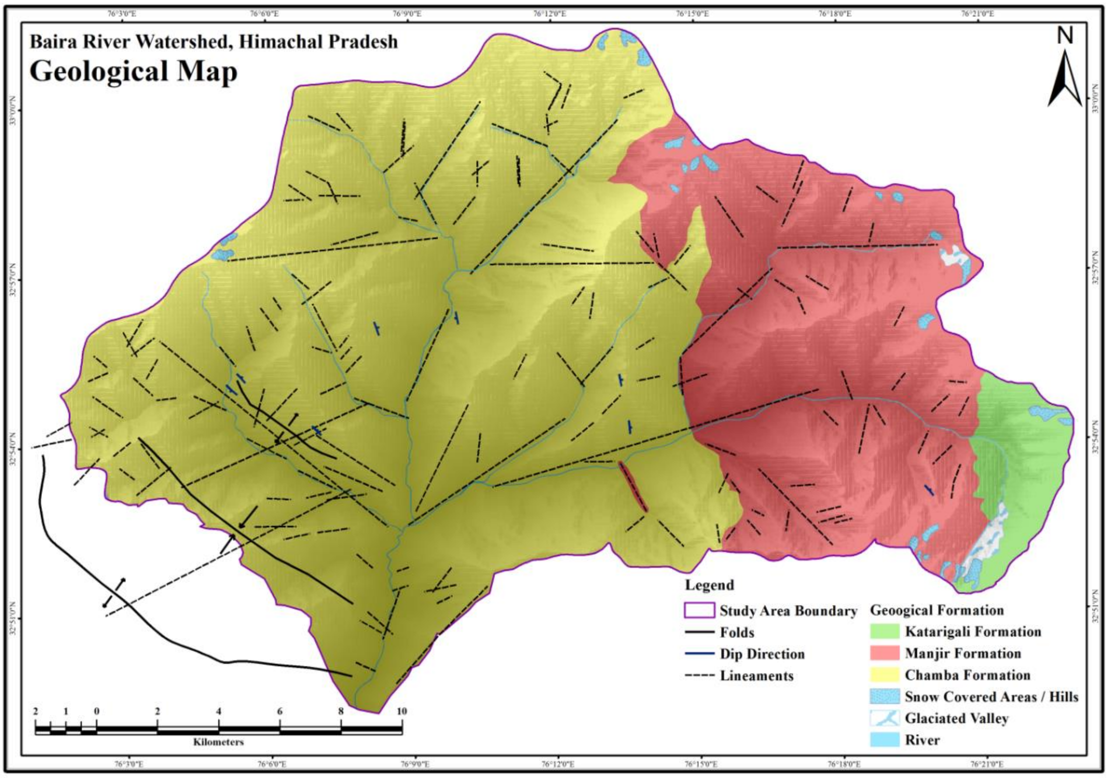

Figure 4. Geological map

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3.6. APPLIED GEOMORPHOLOGY

The term of applied geomorphology implies the utilization of our geomorphological information in fervor of the general public or the humankind in general. This science demonstration like a bridge to some of the gaps that have segregated the several disciplines of the geomorphology. It covers those aspects of the geomorphology that are specifically related with environment issues and decision making processes which are of value of agricultural researchers, engineers, geologists and hydrologists and in addition geomorphologists.

The key application of geomorphology in the study area has been observed. for example, soil erosion, various types of slope failure, river floods, volcanoes, earth-quakes and faulting as natural hazards. Now and then we found the result of the utilization of main procedures impulsively somehow, specifically, if there is an occurrence of soil erosion and man-made problem. Earthquakes (natural problems) in such conditions can be the role of expert geomorphologist that comes in picture since they would be able to measure of comprehension of the combinations of occasions that created the hazards.

Satellite remote sensing data, aerial photographs, digital elevation model and digital terrain model is an important tool for preparation of geomorphological map. The geomorphological map is can be prepared from small scale 1:1 million to a larger scale of 1:1,000 but it is depending on the scope, scale, purpose and nature of problems the geomorphological map. The detailed geomorphological map of the study area has been prepared through visual image interpretation of satellite data (*i.e.* IRS-P6 ResourceSAT-1 LISS-III, LandSAT-7 ETM$^+$ and LandSAT-8 PAN & OLI merge data) (See **Figure 5**), digital elevation models (*i.e.* IRS-P5 CartoSAT-1 DEM, ASTER DEM data), sol topographical maps of 1: 50,000 scale, and GSI geological map (structural and lithological).

The various geomorphic units and their component were identified and mapped (**Figure 6**). The important geomorphic units, their lithology and description/ characteristics are shown in **Table 3**.

3.7. MORPHOMETRIC ANALYSIS

Horton and Strahler were the first geomorphologists, who measured the various morphometric parameters of river basin. (Horton, 1945; Strahler, 1952) Morphometric analysis is the mathematical measurement of configuration of the earth surface, shape, and dimension of its landforms in a given drainage basin. Landforms and morphometric analyses are significant in the study of geomorphology with the quantitative measurements of physical characteristics of landforms to understand the structure, processes and evolution of landscape. It is also help to comprehension the hydrological behavior of drainage basin and controlled the predominantly climate, geology, geomorphology, structural backgrounds of the river basin.

The morphometric characteristics at the river basin scale may contain essential information in regards to its formation and development since all hydrologic and geomorphic processes occur within the river basin. The relationship between various morphometric parameters and the above-mentioned factors are well recognized by various geomorphologists (Rich, 1916; Wenthworth, 1930; Horton, 1932; Strahler, 1952; Taylor & Schwarz, 1952; Potter, 1957; Schumm, 1956; Chorley, 1957; Hack, 1957; Melton, 1958; Farvolden, 1963; Smart &

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Surkan, 1967; Faniran, 1968; Mueller, 1968; Black, 1972; Moore & Thornes, 1976; Patton & Baker, 1976; Pareta, 2004). They have documented that relations are very significant between hydrological characteristics, geological and geomorphic characteristics of river basin system. Several key hydrologic phenomena can be linked with the physiographic characteristics of river basin such as size, shape, geometry, drainage density, relief, slope of drainage area, size and length of the contributories *etc.* (Rastogi & Sharma, 1976). The quantitative analysis of morphometric parameters is found to be of huge utility in river basin evaluation, watershed prioritization for soil and water conservation and natural resources management. The morphometric analysis of the Baira river watershed has been carried out based on satellite remote sensing data (*i.e.* IRS-P6 ResourceSAT-1 LISS-III, LandSAT-7 ETM$^+$ and LandSAT-8 PAN & OLI merge data), digital elevation models (*i.e.* IRS-P5 CartoSAT-1 DEM, ASTER DEM data), and soI topographical maps of 1: 50,000 scale. The drainage network with stream order has been generated by using above stated DEM data and rectified its using SoI topographical maps through ArcGIS-10.3 software. Stream ordering has been generated using (Strahler, 1952) system, and ArcHydro tool in ArcGIS-10.3 software. First time in the world, authors have investigated "One-Hundred and Seventy-Three Morphometric Parameters" of a single watershed. Out of 173 parameters, 54 morphometric parameters have been directly analysed and generated in ArcGIS-10.3 software. Morphometric parameters of Baira river watershed with formula, references and result are shown in **Table 4**.

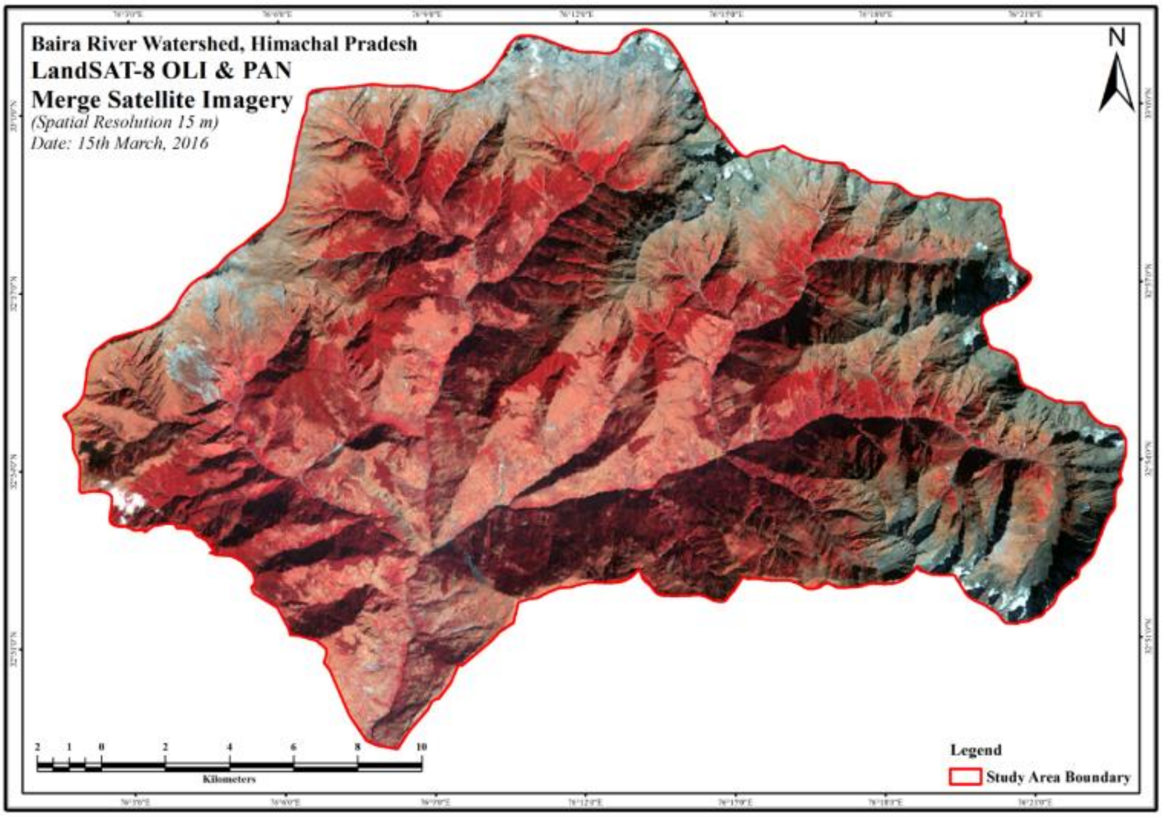

Figure 5. LandSAT-8 PAN & OLI merge satellite

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Tabel 1. Important geomorphic units of the Baira river watershed conditions

S. No.	Geomorphic Units or Landforms	Map Symbol	Lithology	Description / Characteristic
1.	Valley Fills	VF	Shale, Sandstone and Limestone	The unconsolidated sediment deposited to fill a valley, sometimes controlled by fracture forming linear depression.
2.	Pediplain (Katarigali)	PP (KG)	Katarigali Formation: Dark Grey Slate, Micaceous Sandstone and Quartzite	Thin soil covered erosional surface developed over meta-sedimentary rock *i.e.* quartzite, slate, *etc.* Low relief, gently sloping, undulating terrain.
3.	Buried Pediment (Manjir Sedimentary)	BP (MN) SST	Manjir Formation: Slate, Shale, Sandstone and Limestone	Broad, gently sloping, erosional surface covered with detritus of sandstone, shale and thin veneer of soil.
4.	Pediment (Chamba)	PM (CB)	Chamba Formation: Slate, Phyllite Carbonaceous Slate and Quartzite	Broad, gently to moderate sloping, erosional surface covered with detritus of sedimentary rocks.
5.	Structural Valley (Manjir)	SV (MN)	Manjir Formation: Slate, Shale, Sandstone and Limestone	Low to moderate relief undulating topography. Normally cultivated soil thickness varies from place to place.
6.	Sandstone Upland (Katarigali)	SST(KG)	Katarigali Formation: Dark Grey Slate, Micaceous Sandstone and Quartzite	Deep sites with sand, slate on uplands. Narrow sites on slopes of hills, scarps and valley sides. Moderate to high sloping.
7.	Sandstone Upland (Manjir)	SST(MN)	Manjir Formation: Slate, Shale, Sandstone and Limestone	Narrow sites on slopes of hills, scarps and valley sides. Moderate to high sloping. Deep sites with sand, slate, shale, limestone on uplands.
8.	Sandstone Upland (Chamba)	SST(CB)	Chamba Formation: Slate, Phyllite Carbonaceous Slate and Quartzite	Narrow sites on slopes of hills, scarps and valley sides. Moderate to high sloping. Deep sites with slate, sand, quartzite.
9.	Denudational Hills (Katarigali)	DHM (KG)	Katarigali Formation: Dark Grey Slate, Micaceous Sandstone and Quartzite	High relief, moderate to steep slope, barren, moderate to high hills. Generally seen sand, slate and quartzite.
10.	Denudational Hills (Manjir)	DHM (MN)	Manjir Formation: Slate, Shale, Sandstone and Limestone	High relief, moderate to steep slope, barren, moderate to high hills. Generally seen sand, slate, shale and limestone.
11.	Denudational Hills (Chamba)	DHM (CB)	Chamba Formation: Slate, Phyllite Carbonaceous Slate and Quartzite	High relief, moderate to steep slope, barren, moderate to high hills. Generally seen sand, slate and quartzite.
12.	Structural Hills (Katarigali)	SH (KG)	Katarigali Formation: Dark Grey Slate, Micaceous Sandstone and Quartzite	Very high relief, steep sloping, barren, covered with natural vegetation with slate, sand and quartzite.
13.	Structural Hills (Manjir)	SH (MN)	Manjir Formation: Slate, Shale, Sandstone and Limestone	Very high relief, steep sloping, barren, Covered with natural vegetation with slate, shale, sand, and limestone.
14.	Structural Hills (Chamba)	SH (CB)	Chamba Formation: Slate, Phyllite Carbonaceous Slate and Quartzite	Very high relief, steep sloping, barren, Covered with natural vegetation with slate and quartzite.
15.	River	R	-	Baira river and its tributaries *i.e.* Malin Nadi, Cheni Nala, Trishan Nala, Tabriyali Nala, Bhusandu Nala and Chhawed Nala.
16.	Snow Covered Areas	SC	-	Snow covered areas and hills.
17.	Glaciated Valley	GV	-	Glaciated valley.
18.	Fold, Fault	--------	-	Quartz intrusions that cut across the country rock Phyllite Slate and Quartzite.
19.	Lineaments	--------	-	Fractures, joints, shear zone, contact zones, other linear features and straight stream courses

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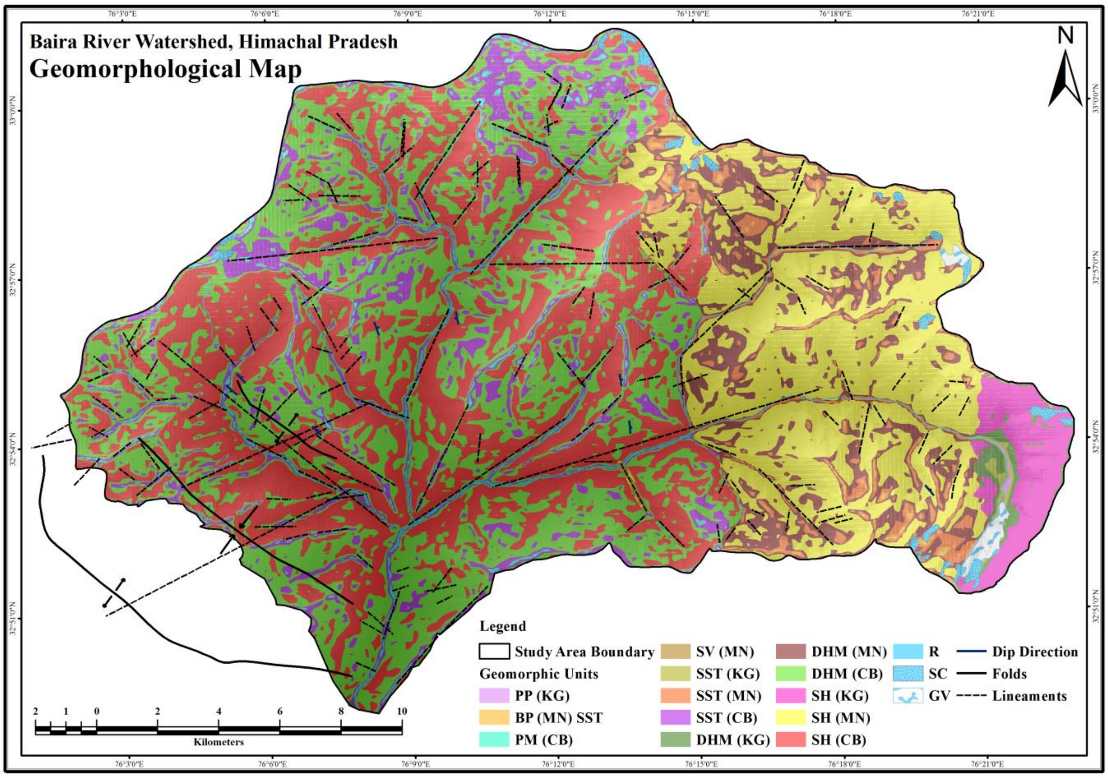

Figure 6. Geomorphological map

Tabel 4. Comparison of drainage basin characteristics of Baira river watershed

S. No.	Morphometric Parameter	Formula	Reference	Result
A	**Drainage Network**			
1	Stream Order (Su)	Hierarchical Rank	(Strahler,1952)	1 to 7
2	Total No. of 1st Order Stream (Suf1)	Suf1 = N1	(Strahler, 1952)	1580
3	Total No of 2nd Order Stream (Suf2)	Suf2 = N2	(Strahler, 1952)	371
4	Stream Number (Nu)	Nu = N1+N2+ ……Nn	(Horton, 1945)	2074
5	Left Bank Tributaries Stream Number (Nulb)	Nulb = N1lb + N2lb + …….Nnlb	(Horton, 1945)	1233
6	Right Bank Tributaries Stream Number (Nurb)	Nurb = N1rb + N2rb + …….Nnrb	(Horton, 1945)	841
7	Stream Number Symmetry Index (Nusi)	Nusi = Nulb / Nurb	(Pareta, 2004)	1.47
8	Total Length of 1st Order Stream (L1)	L1	(Horton, 1945)	875.75
9	Total Length of 2nd Order Stream (L2)	L2	(Horton, 1945)	252.89
10	Stream Length (Lu) Kms	Lu = L1+L2 …… Ln	(Strahler, 1952)	1333.91
11	Average Length of First Order Stream (Lu1)	Lu1 = L1 / N1	(Strahler, 1952)	0.55
12	Average Length of Second Order Stream (Lu2)	Lu2 = L2 / N2	(Strahler, 1952)	0.68
13	Ratio between Average Lengths of First to Second Order Streams [Lu(1/2)]	Lu(1/2) = Lu1 / Lu2	(Strahler, 1952)	0.81
14	Stream Length Ratio (Lur)	Lur = Lu / (Lu+1)	(Strahler, 1952)	1.43 to 3.46
15	Mean Stream Length Ratio (Lurm)	Lurm = Σ Lur / Max Su-1	(Horton, 1945)	2.37
16	Weighted Mean Stream Length Ratio (Luwm)	Luwn = Σ[Lur * (Lu + (Lu+1))] / Σ [Lu + (Lu+1)]	(Horton, 1945)	3.04
17	Left Bank Tributaries Stream Length (Lulb)	Lulb = L1lb + L2lb + …….Lnlb	(Strahler, 1952)	839.35
18	Right Bank Tributaries Stream Length (Lurb)	Lurb = L1rb + L2rb + …….Lnrb	(Strahler, 1952)	494.56

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Tabel 4. (*continued*) Comparison of drainage basin characteristics of Baira river

S. No.	Morphometric Parameter	Formula	Reference	Result
19	Stream Length Symmetry Index (Lusi)	Lusi = Lulb / Lurb	(Pareta, 2004)	1.70
20	Bifurcation Ratio (Rb)	Rb = Nu / (Nu+1)	(Strahler, 1952)	2.33 to 4.26
21	Mean Bifurcation Ratio (Rbm)	Rbm = Σ Rb / Max Su-1	(Strahler, 1952)	3.54
22	Weighted Mean Bifurcation Ratio (Rbwm)	Rbwm = [Lu+(Lu+1)] / [Rb * {Lu+(Lu+1)}]	(Strahler, 1952)	4.08
23	Left Bank Tributaries Bifurcation Ratio (Rblb)	Rblb = Nulb / (Nulb+1)	(Strahler, 1952)	3.80
24	Right Bank Tributaries Bifurcation Ratio (Rbrb)	Rbrb = Nurb / (Nurb + 1)	(Strahler, 1952)	3.07
25	Bifurcation Ratio Symmetry Index (Rbsi)	Rbsi = Nulb / Nurb	(Pareta, 2004)	1.24
26	Main Channel Length (Cl) Kms	GIS Software Analysis	-	25.91
27	Flow Path Length (Lfp) Kms	GIS Software Analysis	-	24.99
28	Valley Length (Vl) Kms	GIS Software Analysis	-	23.53
29	Minimum Aerial Distance (Adm) Kms	GIS Software Analysis	-	23.81
30	Channel Index (Ci)	Ci = Cl / Adm (H & TS)	(Miller, 1968)	1.09
31	Valley Index (Vi)	Vi = Vl / Adm (TS)	(Miller, 1968)	0.99
32	Rho Coefficient (ρ)	ρ = Lur / Rb	(Horton, 1945)	0.98
33	Angle of the 1st Order Stream (An1)	GIS Software Analysis	(Schumm, 1956)	72.23 (Average)
34	Junction Ratio (Jr)	GIS Software Analysis	(Schumm, 1956)	0.53
35	Law of Junction Angle (Aμ)	Aμ = An1 * Jr (μ-1)	(Schumm, 1956)	38.55
B	**Basin Geometry**			
36	Length from WS Center to Mouth of WS (Lcm) Kms	GIS Software Analysis	(Black, 1972)	13.03
37	Width of WS at the Center of Mass (Wcm) Kms	GIS Software Analysis	(Black, 1972)	16.81
38	Basin Length (Lb) Kms	GIS Software Analysis	(Schumm, 1956)	23.53
39	Mean Basin Width (Wb)	Wb = A / Lb	(Horton, 1932)	18.07
40	Basin Area (A) Sq Kms	GIS Software Analysis	(Schumm, 1956)	425.25
41	Mean Area of 1st Order Stream (Am1)	GIS Software Analysis	-	0.18
42	Stream Order wise Mean Area (Am)	DEM & GIS Software Analysis	-	0.92
43	Mean Area Ratio (Arm)	Arm = Am / (Am+1)	-	0.68
44	Weighted Mean Area Ratio (Arwm)	Arwn = Σ[Su * Nu] / Σ[Am *Arm]	-	0.77
45	Basin Perimeter (P) Kms	GIS Software Analysis	(Schumm, 1956)	99.17
46	Relative Perimeter (Pr)	Pr = A / P	(Schumm, 1956)	4.29
47	Length Area Relation (Lar)	Lar = 1.4 * $A^{0.6}$	(Hack, 1957)	52.88
48	Lemniscate's (k)	k = Lb^2 / A	(Chorley *et al.*, 1957)	1.30
49	Form Factor Ratio (Rf)	Ff = A / Lb^2	(Horton, 1932)	0.77
50	Shape Factor Ratio (Rs)	Sf = Lb^2 / A	(Horton, 1932)	1.30
51	Elongation Ratio (Re)	Re = 2 / Lb * $(A / \pi)^{0.5}$	(Schumm, 1956)	0.99
52	Elipticity Index (Ie)	Ie = π * Vl^2 / 4 A	-	1.02
53	Texture Ratio (Rt)	Rt = N1 / P	(Schumm & Lichty, 1965)	15.93
54	Circularity Ratio (Rc)	Rc = 12.57 * (A / P^2)	(Potter, 1957)	0.54
55	Circularity Ration (Rcn)	Rcn = A / P	(Strahler, 1952)	4.29
56	Drainage Texture (Dt)	Dt = Nu / P	(Horton, 1945)	20.91
57	Compactness Coefficient (Cc)	Cc = 0.2841 * P / $A^{0.5}$	-	1.37
58	Fitness Ratio (Rfi)	Rf = Cl / P	(Melton, 1958)	0.26
59	Wandering Ratio (Rw)	Rw = Cl / Lb	(Smart & Surkan, 1967)	1.10
60	Watershed Eccentricity (τ)	τ = $[(\lvert Lcm^2 - Wcm^2 \rvert)]^{0.5}$/Wcm	(Black, 1972)	0.76
61	Centre of Gravity of the Watershed (Gc)	GIS Software Analysis	(Rao, 1998)	76.204 E & 32.921 N

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Tabel 4. (*continued*) Comparison of drainage basin characteristics of Baira river

S. No.	Morphometric Parameter	Formula	Reference	Result
62	Hydraulic Sinuosity Index (Hsi) %	Hsi = ((Ci - Vi)/(Ci - 1))*100	(Mueller, 1968)	113.33
63	Topographic Sinuosity Index (Tsi) %	Tsi = ((Vi - 1)/(Ci - 1))*100	(Mueller, 1968)	-13.33
64	Standard Sinuosity Index (Ssi)	Ssi = Ci / Vi	(Mueller, 1968)	1.10
65	Longest Dimension Parallel to the Principal Drainage Line (Clp) Kms	GIS Software Analysis	-	25.92
66	Area of the Basin to the Right of the Trunk Stream that Facing Downstream (Ar) Sq Kms	GIS Software Analysis	-	169.62
67	Distance from the Midline of the Drainage Basin to the Midline of the Active Meander Belt (Damb)	GIS Software Analysis	(Cox, 1994)	11.34
68	Distance from the Basin Midline to the Basin Divide (Dbd)	GIS Software Analysis	(Cox, 1994)	4.41
69	Area of Left Bank Tributaries (Alb) Sq Kms	GIS Software Analysis	-	255.63
70	Area of Right Bank Tributaries (Arb) Sq Kms	GIS Software Analysis	-	169.62
71	Drainage Basin Asymmetry (Bas)	Bas = 100 (Ar / A)	-	39.89
72	Transverse Topographic Symmetry Factor (TTSF)	TTSF = Damb / Dbd	(Cox, 1994)	2.57
73	Ratio of First Order Stream Number to Perimeter (PN1)	PN1 = N1 / P	-	15.93
74	Basin Area Symmetry Index (Bsi)	Bsi = Alb / Arb	(Pareta, 2004)	1.51
75	Valley Width (Vwid) Mts	Vwid = Valley width 0.5 Km from basin mouth	-	4.83
76	Meander Width Ratio (MWR)	GIS Software Analysis	-	1.52
77	Stream Meander Length (Lm)	GIS Software Analysis	-	23.81
78	Meander Length Ratio (Lmr)	Lmr = Lm / MWR	-	15.66
79	2D Area of Watershed (A2d) Sq Kms	3D Analyst-Surface Volume Tool in ArcGIS-10.3	-	423.72
80	3D Arrea of Watershed (A3d) Sq Kms	A3d = 2D Area / Cosine (Slope in degrees)	-	527.62
81	Watrshed Volume (Vw) Cubic Meter	3D Analyst-Surface Volume Tool in ArcGIS-10.3	-	811569.78
C	**Drainage Texture Analysis**			
82	Stream Frequency (Fs)	Fs = Nu / A	(Horton, 1932)	4.88
83	Drainage Density (Dd) Km / Kms^2	Dd = Lu / A	(Horton, 1932)	3.14
84	Constant of Channel Maintenance (Kms^2 / Km) C	C = 1 / Dd	(Schumm, 1956)	0.32
85	Drainage Intensity (Di)	Di = Fs / Dd	(Faniran, 1968)	1.55
86	Infiltration Number (If)	If = Fs * Dd	(Faniran, 1968)	15.30
87	Drainage Pattern (Dp)	-	(Horton, 1932)	Dendritic, Radial
88	Length of Overland Flow (Lg) Kms	Lg = A / (2 * Lu)	(Horton, 1945)	0.16
89	Flow Direction (Fdi)	Spatial Analyst-Hydrology Tool in ArcGIS-10.3	-	NW to SE
90	Flow Accumulation (Range in M) Fac	Spatial Analyst-Hydrology Tool in ArcGIS-10.3	-	703 to 35,855
91	Basin-scale Ruggedness (Rbs)	Rbs = A / Dd	-	135.57
92	1^{st} Order Stream Frequency (Fst)	Fst = N1 / A	(Miller, 1968)	3.72
D	**Relief Characterizes**			
93	Height of Basin Mouth (Zbm) M	GIS Analysis / DEM	-	1178
94	Minimum Height in the Basin (Zmi) M	GIS Analysis / DEM	-	1155
95	Maximum Height of the Basin (Zmx) M	GIS Analysis / DEM	-	5268
96	Mean Height Value (Hmv)	Summary Statistics for WS	-	3206.17

Tabel 4. (*continued*) Comparison of drainage basin characteristics of Baira river

S. No.	Morphometric Parameter	Formula	Reference	Result
		Raster; not median / GIS Software		
97	Total Basin Relief (H) m	H = Zmx – Zbm	(Strahler, 1952)	4090
98	Relief Ratio (Rhl)	Rhl = (H / Lb) / 100	(Schumm, 1956)	1.74
99	Absolute Relief (Ra) m	GIS Analysis / DEM	-	1155
100	Relative Relief Ratio (Rhp)	Rhp = (H * 100) / P	(Melton, 1958)	4124.23
101	Average Divide Elevation (Eda)	Eda = H / Rhl	-	2353
102	Divide Average Relief (Rad)	Rad = Eda – Zbm	(Farvolden, 1963)	1175
103	Dissection Index (Dis)	Dis = H / Ra	-	3.54
104	Channel Gradient (Cg) m / Kms	Cg = H / {(π/2) * Clp}	-	50.22
105	Gradient Ratio (Rg)	Rg = (Zmx - Zmi) / Lb	(Sreedevi, 2004)	174.80
106	Watershed Slope (Sw)	Sw = H / Lb	-	173.82
107	Ruggedness Number (Rn)	Rn = Dd * (H / 1000)	(Patton & Baker, 1976)	12.83
108	Melton Ruggedness Number (MRn)	MRn = H / $A^{0.5}$	(Melton, 1965)	198.34
109	Total Contour Length (Ctl) Kms	GIS Software Analysis	-	12869.96
110	Contour Interval (Cin) m	GIS Software Analysis	-	20
111	Plan Curvature (Plc)	Curvature - 3D Analyst Tools in ArcGIS-10.3	(Moore & Thornes, 1976)	Ranging from (+) 19.16 to (-) 17.42
112	Length of Two Successive Contours (L1+L2) Km	GIS Software Analysis	(Strahler, 1952)	107.95
113	Average Width between Two Successive Contours (Awc)	Awc = A / {(L1+L2) / 2}	(Strahler, 1952)	9.90
114	Stream Length-Gradient Index (SLgi) in M	SLgi = (Zmx - Zmi) * Lfp	(Azor *et al.*, 2002)	164.59
115	Mean Stream Channel Gradients (Smcg)	Smcg = H / Cl	-	157.85
116	Slope Analysis (Sa)	GIS Analysis / DEM	(Rich, 1916)	$5^0$0'-$47^0$3'
117	Average Slopes of 1st Order Streams (AS1)	GIS Analysis / DEM	(Sreedevi *et al.*, 2009)	35.89
118	Slope Gradient (tan β) ^{0}	GIS Analysis / DEM	-	27.33
119	Maximum Slope Value Raster (Smax)	GIS Analysis / DEM	-	68.21
120	Minimum Slope Value Raster (Smin)	GIS Analysis / DEM	-	2.38
121	Slope Variability (Sva)	Sva = Smax – Smin	-	65.83
122	Slope Index (Sin)	Sin = H / Lb	(Taylor & Schwarz, 1952)	173.82
123	Slope Ration (Sr)	Sr = AS1 / (AS1+1)	(Sreedevi *et al.*, 2009)	0.97
124	Profile Curvature (CuPr)	Curvature - 3D Analyst Tools in ArcGIS-10.3	-	Ranging from (+) 16.19 to (-) 18.22
125	Platform Curvature (CuPl)	Curvature - Spatial Analyst in ArcGIS-10.3	-	Ranging from (+) 35.22 to (-) 31.55
126	Slope Aspect (Sas)	3D Analyst Tools in ArcGIS-10.3	-	South (157.5-202.5)
127	Average Slope (S) %	S = (Z * (Ctl/H)) / (10 * A)	(Wenthworth's, 1930)	3.90
128	Hack's Stream-Length (SLh)	SLh = (Δ H / Δ Lu) / Lu	(Hack, 1973)	0.0023
129	Mean Slope Ratio (Sm)		(Wenthworth's, 1930)	2.03
130	Weighted Mean Slope Ratio (Swm)		(Wenthworth's, 1930)	2.64
131	Mean Slope of Overall Basin (ϴs)	ϴs = (Ctl * Cin) / (A * 100)	(Chorley *et al.*,	6.05

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Tabel 4. (*continued*) Comparison of drainage basin characteristics of Baira river

S. No.	Morphometric Parameter	Formula	Reference	Result
			1957)	
132	Length-Slope Factor (LSf)	LSf = 1.4 * [(A/22.13)^0.4] * [(tan β / 0.0896)^1.3]	(Moore & Wilson, 1992)	7748.62
133	Topographic Wetness Index (TWI) or Compound Topographic Index (CTI) or Topographic Moisture Index (TMI) or Hillslope Wetness Index (HWI)	TWI = ln (A / tan β)	(Moore *et al.*, 1991)	15.00
134	Upslope Contributing Area per Unit Contour Length (Aus)	Aus = Ctl / A	(Moore *et al.*, 1991)	30.26
135	Relative Stream Power (SPr)	SPr = Aus * tan β	(Lindsay, 2005)	827.13
136	Stream Power Index (SPI)	SPI = A * tan β or SPI = Ln(((FlowAccum_Raster) + 0.001) * ((Slope_Raster)/100) + 0.001)) *(in ArcGIS 10.3)*	(Moore *et al.*, 1993)	15.560
137	Topographic Position Index (TPI) or Relative Topographic Position (RTP) or Local Elevation Index (LEI)	TPI = ("smtDEM" - "minDEM") / ("maxDEM" - "minDEM"), where: minDEM = Name of minimum elevation raster, maxDEM = Name of maximum elevation raster, smtDEM = Name of smoothed elevation raster	(Jenness, 2005)	Ranging from (+) 341.23 to (-) 301.81 at 50m nb
138	Slope Position Classification (SPC)	Topography Tools in ArGIS-10.3	(Jenness, 2005)	Valleys, cliff base, mid slope, ridge / hilltop / canyon edge
139	Landform Classification (LC)	Topography Tools in ArGIS-10.3	(Jenness, 2005)	Canyons, deeply incised streams, upland drainages, high ridges / hills
140	Topographic Convergence Index (TCI)	Ln (flow accum+1) / (tan(((slope Deg.) * 3.141593) / 180))	-	18.99
141	Terrain Characterization Index (TCHi)	TCHi = TCI * In Aus	(Park *et al.*, 2001)	64.75
142	Length along the Edge of the Mountain Piedmont Junction (Lmej)	GIS Software Analysis	-	49.585
143	Overall Length of the Mountain Front (Lmf)	GIS Software Analysis	-	11.765
144	Mountain Front Sinuosity Index (Simf)	Simf = Lmej / Lmf	-	4.21
145	Terrain Roughness Index (TRI)	TRI = √(Abs((FS3x3max)^2) - ((FS3x3max)^2)), where: FS3x3max = Focal statistics of DEM with 3m size / type minimum, FS3x3max = Focal statistics of DEMwith 3m size / type maximum	(Riley, 1999)	Highly Rugged
146	Relative Height (h/H)	h/H	(Strahler, 1952)	100 to 0

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Tabel 4. (*continued*) Comparison of drainage basin characteristics of Baira river

S. No.	Morphometric Parameter	Formula	Reference	Result
147	Relative Area (a/A)	a/A	(Strahler, 1952)	0 to 100
148	Hypsometric Index (HI)	HI = (Hmv - Zmi) / (Zmx - Zmi)	-	0.50
149	Hypsometric Integral (Hi) %	Hypsom Curve h/H & a/A	(Strahler, 1952)	58.33
150	Erosional Integral (Ei) %	Hypsom Curve h/H & a/A	(Strahler, 1952)	41.67
151	Stage of Watershed (WSs)	According to Hypsometric Integral	(Strahler, 1952)	Mature
152	Clinographic Analysis (Clga)	Tan Q = Cin / Awc	(Strahler, 1952)	2.02
153	Erosion Surfaces (Es) m	Superimposed Profiles	(Potter, 1957)	2610, 3130, 3450, 3900 & 4705
154	Surface Area of Relief (Rsa) Sq Kms	Composite Profile	-	331.77
155	Composite Profile Area (Acp) Sq Kms	Area between the Composite Curve and Horizontal Line	(Pareta, 2004)	331.77
156	Minimum Elevated Profile Area as Projected Profile (App) Sq Kms	Area between the Minimum Elevated Profile as Projected Profile and Horizontal Line	(Pareta, 2004)	105.84
157	Erosion Affected Area (Aea) Sq Kms	Aea = Acp - App	(Pareta, 2004)	225.93
158	Total Soil Loss (SE) [Tonnes/Hectare/Year]	TSL = R*K*LS*C*P	-	145.12
159	Longitudinal Profile Curve Area (A_1) Sq Kms	Area between the Curve of the Profile and Horizontal Line	(Snow & Slingerland, 1987)	122.05
160	Profile Triangular Area (A_2) Sq Kms	Triangular Area created by that Straight Line, the Horizontal Axis Traversing the Head of the Profile	(Snow & Slingerland, 1987)	211.84
161	Concavity Index (Ca)	$Ca = A_1 / A_2$	(Snow & Slingerland, 1987)	0.58
162	Sediment Transport Capacity Index (STCI)	STCI = [1.4 * ((A / 22.13)^0.4)] * [(tanβ / 0.0896)^1.3]	(Moore *et al.*, 1991)	7748.62
163	Mean Ground Slope Angle (Sma) Degree		-	33.50
164	Sediment Area Factor (Saf)	$Saf = P / \cos \Theta_{Sma}$	(Lustig, 1966)	118.93
165	Sediment Movement Factor (Smf)	$Smf = Saf * \cos \Theta_{Sma}$	(Lustig, 1966)	99.17
166	Transport Efficiency Factor (Tef)	Tef = Rbm * Σ Lu	(Lustig, 1966)	0.0027
167	Sediment Yield (Sy) Metric Tons Kms^{-2} yr^{-1}	Sy = ƒ (Saf, Smf, Tef)	(Lustig, 1966)	218.10
168	Elevation of the Valley Floor or Stream Channel (Esc) Mts	GIS Software Analysis	-	1314.00
169	Elevations of the Left Valley Divides (Elvd) Mts	GIS Software Analysis	-	2783.00
170	Elevations of theRight Valley Divides (Ervd) Mts	GIS Software Analysis	-	4278.00
171	Valley Floor Width to Valley Height Ratio (Vf)	Vf = (2 * Vwid) / ((Elvd - Esc) + (Ervd - Esc))	-	0.0022
172	Hillslope Erosion Potential (HEP)	HEP = (Pma * S) / 1000, where, Pma (Mean Annual Precipitation): 860.95 mm (Chamba)	(Mitchell & Montgomery, 2006)	3.36
173	Specific Weight of Sediment (Quartz) γs	Density relative to Water (1.65 Constant for Quartz)	-	1.65

3.8. CORRELATION ANALYSIS OF DRAINAGE MORPHOMETRIC CHARACTERISTICS

Statistics analyses are useful in a variability of fields in hydrological research. These analyses are valuable for understanding of morphometric parameters and linking the same to particular hydrological forms. Statistical analysis of inter-relationship of morphometric parameters are help to understanding the terrain characteristics for hydrological potential at micro-watershed level as well watershed management and planning.

A correlation matrix **Table 5** of Baira river watershed and its 95 micro-watershed (MSW) has been generated with the selected 13 morphometric parameters (*i.e.* Area (A), perimeter (P), stream number (Nu), stream length (Lu), form factor (Ff), shape factor (Sf), elongation ratio (Re), texture ratio (Rt), circularity ratio (Rc), drainage texture (Dt), stream frequency (Fs), drainage density (Dd), length of overland flow (Lg)). The preliminary observation is confirmed by the statistics as shown in **Table 5**; furthermost of the morphometric parameters of the Baira river watershed are showing a positive correlation with each other that means these parameters are co-dependent on another, except shape factor and length of overland flow. Shape factor and length of overland flow are demonstrating a negative relationship with other morphometric parameters implies these parameters are independent and it is possible to compelling by different components.

3.9. HYDROLOGICAL POTENTIALITY ZONE

Keeping in mind to identify, categorize, arrange and delineate hydrological potentiality zone in the Baira river watershed, a thorough comprehensive analysis was attempted, which takes several MSW level geo-morphometric parameters map composites into thought by method for integrating and evaluating them based on specific criteria employed. Several thematic data layers have been generated and integrated based on the weightage criteria produced for determination of the hydrological potential zones for surface water, and additionally groundwater investigation in the Baira river watershed. The weightages were relegated to the themes and units relying on their significance of hydrological potentiality area. Hydrological potentiality zones of the Baira river watershed has been generated by using ArcGIS 10.3 software in the model builder module, which has allowed for the amalgamation of different data layers. Weightage criteria used for generation of hydrological potentiality zones are shown in the **Table 6**.

Tabel 5. Correlation matrix of morphometric parameters

Morphometric Parameters		A	P	Nu	Lu	Ff	Sf	Re	Rt	Rc	Dt	Fs	Dd	Lg
1	A	1.00	0.66	0.43	0.68	0.26	-0.36	0.30	0.25	0.19	0.23	-0.04	0.01	-0.03
2	P		1.00	0.37	0.54	-0.31	0.16	-0.27	0.04	-0.51	0.04	0.02	0.08	-0.10
3	Nu			1.00	0.91	0.23	-0.27	0.25	0.93	0.09	0.93	0.85	0.08	-0.71
4	Lu				1.00	0.28	-0.33	0.30	0.78	0.12	0.78	0.61	0.71	-0.68
5	Ff					1.00	-0.94	0.99	0.43	0.83	0.45	0.21	0.19	-0.20
6	Sf						1.00	-0.97	0.40	-0.74	-0.42	-0.18	-0.16	0.17
7	Re							1.00	0.43	0.83	0.43	0.23	0.20	-0.19
8	Rt								1.00	0.33	0.93	0.89	0.85	-0.73
9	Rc									1.00	0.33	0.06	0.03	-0.03
10	Dt										1.00	0.93	0.86	-0.73
11	Fs											1.00	0.93	-0.79
12	Dd												1.00	-0.93
13	Lg													1.00

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Where: Area (A), Perimeter (P), Stream Number (Nu), Stream Length (Lu), Form Factor (Ff), Shape Factor (Sf), Elongation Ratio (Re), Texture Ratio (Rt), Circularity Ratio (Rc), Drainage Texture (Dt), Stream Frequency (Fs), Drainage Density (Dd), Length of Overland Flow (Lg)

Tabel 6. Weights of geomorphometric parameters for hydrological potentiality zone

Factor	Values	Weights (W_i)	Remarks
Bifurcation Ratio (Rb)	Less than 2.250	10	The low value of bifurcation ratio is characterize in the high hydrological potential zone because it is depend on geological and lithological development of the drainage basin, and dimensionless property are generally ranges from 3.0 to 5.0.
	2.250 – 2.501	9	
	2.502 – 2.753	8	
	2.754 – 3.004	7	
	3.005 – 3.255	6	
	3.256 – 3.506	5	
	3.507 – 3.758	4	
	3.759 – 4.009	3	
	4.010 – 4.260	2	
	More than 4.260	1	
Elongation Ratio (Re)	Less than 0.670	1	The high value of elongation ratio is characterizing in the high hydrological potential zone because high elongation value is signifying the more elongated of the basin, that means if the basin is more elongated then surface runoff is also high.
	0.671 – 0.881	2	
	0.882 – 0.987	3	
	0.988 – 1.092	4	
	1.093 – 1.198	5	
	1.199 – 1.303	6	
	1.304 – 1.409	7	
	1.410 – 1.514	8	
	1.515 – 1.620	9	
	More than 1.620	10	
Texture Ratio (Rt)	Less than 10.720	10	The low value of texture ratio is described in the high hydrological potential zone because it is depending on the drainage density. Low value of texture ratio is also represent the low drainage density, means low surface runoff.
	10.721 – 12.421	9	
	12.422 – 14.122	8	
	14.123 – 15.823	7	
	15.824 – 17.524	6	
	17.525 – 19.226	5	
	19.227 – 20.927	4	
	20.928 – 22.628	3	
	22.629 – 24.329	2	
	More than 24.329	1	
Drainage Texture (Dt)	Less than 14.071	10	The low value of drainage texture is defined in the high hydrological potential zone because it is depending on the drainage density. Low value of drainage texture is also signifying the low drainage density, means low surface runoff.
	14.072 – 16.304	9	
	16.305 – 18.536	8	
	18.537 – 20.769	7	
	20.770 – 23.002	6	
	23.003 – 25.235	5	
	25.236 – 27.468	4	
	27.469 – 29.701	3	
	29.702 – 31.934	2	
	More than 31.934	1	
Stream Frequency (Fs)	Less than 3.284	10	The low value of stream frequency is demarcated in the high hydrological potential zone.
	3.285 – 3.805	9	
	3.806 – 4.326	8	
	4.327 – 4.847	7	
	4.848 – 5.368	6	

Tabel 6. (*continued*) Weights of geomorphometric parameters for hydrological potentiality zone

Factor	Values	Weights (W_i)	Remarks
	5.369 – 5.889	5	
	5.890 – 6.410	4	
	6.411 – 6.932	3	
	6.933 – 7.453	2	
	More than 7.453	1	
Drainage Density (Dd)	Less than 2.113	10	When drainage is less, there is more possibility of infiltration, and less surface runoff, thereby increasing hydrological potential area.
	2.114 – 2.448	9	
	2.449 – 2.784	8	
	2.785 – 3.119	7	
	3.120 – 3.454	6	
	3.455 – 3.789	5	
	3.790 – 4.125	4	
	4.126 – 4.460	3	
	4.461 – 4.795	2	
	More than 4.795	1	
Slope	Less than 5.00°	10	Steeper slopes (more than 30°) are low prone to hydrological potential area, but the slope below than 12° have high hydrological potential area to the absence of debris over the slope surface.
	05.01° – 9.70°	9	
	09.71° – 14.40°	8	
	14.41° – 19.10°	7	
	19.11° – 23.80°	6	
	23.81° – 28.50°	5	
	25.51° – 33.20°	4	
	33.21° – 37.90°	3	
	37.91° – 42.60°	2	
	More than 42.60°	1	

On the beginning of integration of these data layers' hydrological potentiality zones of the study area were identified. The weightages are assigned for various mapping units of a thematic layers in a scale ranging from 1 to 10, individually, where value 1 demonstrates for least significance while the worth 10 showing highest significance of the mapping unit. The final hydrological potentiality zone map has been displayed in a gradation of red to green. The green patches represent the most potential MWS for water resource development, while the red patches denote the least. The more potential MWS are the ones which have got an aggregate score close to 10. A glance at **Figure 7** reveals that the many patches in the whole watershed and some of the south-eastern parts of the study area have poor hydrological potentiality prospects due to steep slope, and high runoff as compared to the south watershed, north-eastern part, and some part along the river of the basin. These results are also corroborated with observations from the field checks conducted in the basin area.

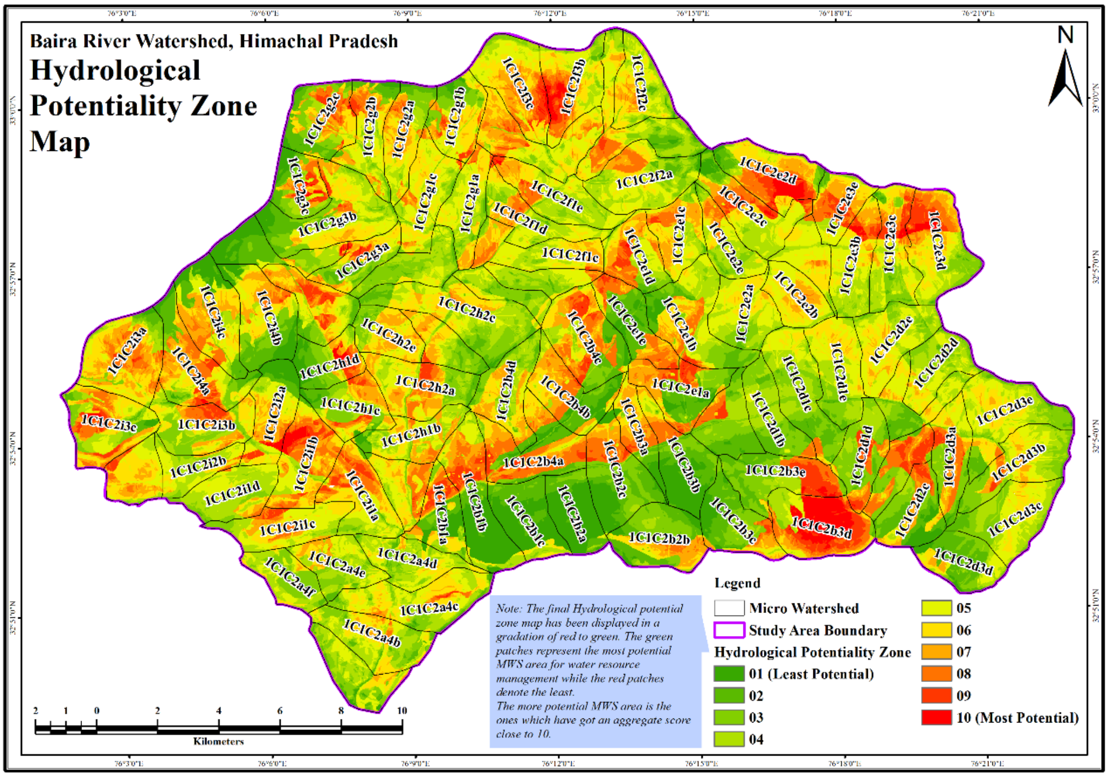

Figure 7. Hydrological potentiality zone map

4. CONCLUSION

Morphometric analysis of watersheds involves the quantification of the drainage network and related parameters such as drainage area, gradient and relief. Quantitative geomorphology finds helpful applications in hydrological investigations related with the flow regime, the rates of erosion and sediment production from watershed. Quantitative Morphometric analysis plays vital role in prediction of hydrological investigations, assessing the sediment yield and to appraise soil erosion rates. The present work is an attempt to carry out a detailed study of linear, areal and relief morphometric parameters in the Baira river watershed, utilizing synergistically the conventional methods and innovative methods *i.e.* Remote Sensing and GIS.

Drainage morphometry of a watershed and micro-watershed (MSW) reflects hydro-geologic development of that river. Satellite remote sensing data has a capacity of getting the succinct perspective of an expansive region at one time, which is extremely helpful in analysing the drainage morphometry. GIS has demonstrated to be an effective device in drainage delineation and this drainage has been utilized as a part of the present study. Frist time in the world total 173 morphometric parameters has been analysed of a single watershed through the measurement of linear, areal and relief aspects of the watershed. Remote Sensing techniques have contributed and will continue contributing tremendously to the state of knowledge about the geomorphometric analysis of micro-watersheds as well as the hydrological scenario assessment and characterization of the watershed and there for better resource and environmental managements.

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6. AUTHORS' NOTE

The author(s) declare(s) that there is no conflict of interest regarding the publication of this article. Authors confirmed that the data and the paper are free of plagiarism.

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