Morphometry and Geomorphological Investigations of the Neugal Watershed, Beas River Basin, Kangra District, Himachal Pradesh Using GIS Tools

S.S.Guleria[1], Naval Kishore[1] and Madhuri, S. Rishi [2]
[1]Center of Advanced Study in Geology, Panjab University, Chandigarh
[2]Department of Environmental Studies, Panjab University, Chandigarh
Corresponding author: madhuririshi@gmail.com

Abstract
An attempt has been made to study the detailed morphometric and geomorphological characteristics of the Neugal Watershed, which is a part of the Beas River Basin, in Kangra district of Himachal Pradesh, India. For detailed study of this watershed, geographical information system (GIS) was used in the evaluation of slope, linear stream ordering and relief aspects of morphometric parameters and also in presentation of geomorphological subdivisions of the basin. Surface Tools in ArcGIS-10 software and ASTER (DEM) were used in the preparation of watershed boundary, slope-aspect and different thematic maps like drainage density, slope and relief. More than eight morphometric parameter of different aspects have been computed. It is observed that the stream frequency decreases as the stream order increases and the densities of 1st order streams are higher in the northern, southern and south-eastern part of the Neugal watershed area. Based on the relationship between absolute and relative relief in the study area, it can be indicated that the relative relief increases with the increase in the absolute relief and shows active correlation. In Neugal watershed, the slope is controlled by the structure, and the erosional processes which have resulted in varied landform leading to environmental hazards.
Keywords: Morphometric parameters, Geomorphological analysis, Neugal watershed, Relief, Environmental hazards

Introduction

Himalaya is a classic example of an orogenic system created by continent–continent collision (Dewey and Bird, 1970; Dewey and Burke, 1973). Its youthfulness and spectacular exposure make the orogen ideal for studying diverse geologic processes related to mountain building. Its potential as a guide to decipher the feedback processes between lithospheric deformation and atmospheric circulation has motivated intense research in recent years on the history of the Himalayan–Tibetan orogen, its role in global climate change, and its interaction with erosion (Harrison et al., 1992, 1998; Molnar et al., 1993; Royden et al., 1997; Ramstein et al., 1997; Tapponnier et al., 2001; Beaumont et al., 2001; Yin et al., 2002). Many workers have also used the Himalayan knowledge to infer the evolution of other mountain belts: the Altai system in central Asia (Yang et al., 1992; Qu and Zhang, 1994), the Trans-Hudson orogen and Canadian Cordillera in North America (Nabelek et al., 2001; Norlander et al., 2002), the Caledonides in Greenland (McClelland and Gilotti, 2003), and the East African–Antarctic orogen in Africa and Antarctica (Jacobs and Thomas, 2004). Despite the broad interests, it has become increasingly daunting for both a beginner and an experienced Himalayan geologist to comprehend the intricate complexity of the Himalayan geology in its entirety. The Himalaya, being tectonically restless, has hyperactive evolutionary characteristics which are worth investigation for effective planning and policy formulation for river basin management. Even a slight obliteration in the eco-balance in the Himalayan environment as a result of human or natural interface cascades down into every sphere of life which certainly has an impact on its impressive bounty and beauty.

The Himalayan Frontal Zone (HFZ) in Himachal Pradesh is a densely populated region, therefore, the geo-environmental system of this area is more intricate and complex in comparison to other areas of the country. It has impact of natural disasters in the past or even the human contribution to influence the fragile eco-system. The Neugal watershed exhibits one of the best and befitting examples of sensitive and delicate geology, geomorphological transformations and dwindling hydrological system. The Neugal watershed lies between the 32^0 05’ to 32^0 15’ N latitudes and 76^0 18’ to 76^0 30’ E longitudes, spreading over an area of approximately 386 km^2 and comprises of Sun, Maul, Janed, Thal and Lingi micro watersheds (Fig.1).

There is a peculiar geological complexity due to the close association of Tertiary and pre-Tertiary rocks in the Neugal Watershed area. This configuration of the complex litho units is very significant from geo-environmental and tectonic point of view. Geo-environmentally, the Neugal watershed is unique for studies because of the conspicuous control of the varied landforms which has resulted from multiple erosional cycles, diverse structures and complex lithology of this river basin. In the present work the Neugal watershed in District Kangra, Himachal Pradesh, has been taken up for the morphometric and geomorphological analysis with the use of remote sensing techniques because of its uniqueness in critical tectonic, geomorphological and environmental condition.

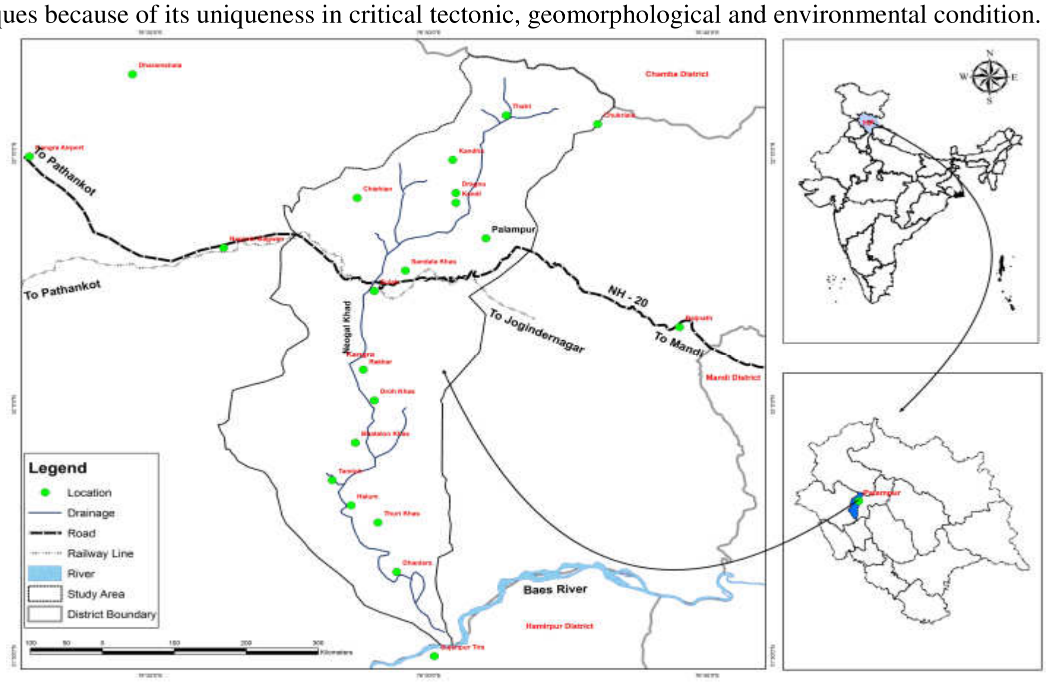

Figure 1. Location Map of the Study Area

Geological setting and Previous work

The Lesser or Outer Himalayan rocks in Himachal Pradesh comprises of undifferentiated Pre-Tertiary i.e. Dalhousie, Dhauladhar, Mandi and Karsog granitoids, Shali and Sundernagar Group and younger sequences of Balani, Infra-Krol, Krol and Tal sequences. The Tertiary rocks comprises of Sabathu, Dagshai and Kasauli formational units. The geological setting of the Neugal Watershed is shows in Table 1. The Siwalik Group of rocks is succeeded by vast stretch of Quaternary alluvium. The Neugal watershed is lithological heterogeneous from north to south and comprises of Dhauladhar granite, Chail metamorphic, Dharamsala traps, Dharamsala sandstones and upper and middle Siwalik conglomerates and valley fill deposits. The Drini thrust, Main Boundary Thrust (MBT) and the Main Central Thrusts (MCT) are conspicuously traversing this region. Towards the southern side the Middle Siwalik sandstone forms the water divide for the Neugal stream, and it in this part of the watershed that the significant Jawalamukhi thrust dissects this watershed. Towards southern tip Neugal meet the Beas River at Sujanpur Tira. The Main Boundary Fault (MBF) restricts the Tertiary formations to the south and Pre-Tertiary formations to the north. Himalayan deformation has led to development of foliations in the gneisses and veins of aplite and pegmatite are also seen cutting the main foliations. At many places xenoliths of phyllites, slate, sandstones and quartzite have also been seen. The exposures of the Dharamsala Formation comprising of maroon sandstone and shales are seen exposed in a linear ridge extending from Chachiyan, Palampur upto Baijnath,-Ehju.

Table-1: Geological setting of the Neugal Watershed,District Kangra, Himachal Pradesh

Quaternary (Post Tertiary)	Glacial and Interglacial Erratic, Moraines and terrace
Tertiary	Siwaliks sandstones, shales and conglomerates
Pre-Tertiary	Intrusive DhaulaDhar granites, gneisses, volcanic rocks, slates, phyllites and schist's, limestone (carbonate) & quartzite

The geology of the Western Himalayas has been studied by number of workers. Important contributions are made by Medlicot (1864); Fiestmanal (1882); McMahon (1882, 1883); Meddlemiss (1896); Pilgrim and West (1928); Wadia (1928); Auden (1934, 1937); Raiverman and Seshavataram (1964); Kanwar (1968); Karunakaran and Ranga Rao (1979); Kumar et al (1989); Mahajan (1991) and Mukhopadhyay et al., (1996). Pal (1998) studied the glacial and neotectonic activity in the western Himalayas. Shah and Paul (1991) divided the Baner and Neugal Watersheds of Kangra valley into ten Geomorphic zones. Shah and Srivastava (1992) studied the morphology and sedimentary facies in Kangra valley. Work on the drainage analysis of Bhed, Brahl, Khauli, Gaj and the Neugal khads of the Kangra valley have been carried out by Naraula et al (1997) where the studies have been restricted to the fluvio-glacial deposits in the Piedmont zone of the valley related to landslides and the neo-tectonic activity. Mahajan and Virdi (2001) have studied the drainage analysis of Churan, Gaj and Banoi khads. Dhar and Dhar (2002) studied the geo-environmental impact of the slate mining in the Dharamsala and its adjoining areas. Further, Dhar et al (2005, 2006) carried out studies basin characteristics of the Baner and Neugal watersheds of the Beas River basin.

Molnar (1987) related Kangra earthquake (1905) to the segmental activity and strain release along slip rupture in the front of the Himalayan foothills extending towards Dehradun. Srivastava (1987) stated that the Dharamsala earthquakes (1968, 1997) were triggered along the transverse strike-slip faults trending NNE-SSW. Kumar and Mahajan (1991) correlated the Dharamsala earthquake (1986) to MBT and Muree Thrust. Since the proposed area needs a proper geo-environmental and morphometric investigations, spatial planning and management, the present work is proposed along the Neugal watershed, Kangra district, Himachal Pradesh.

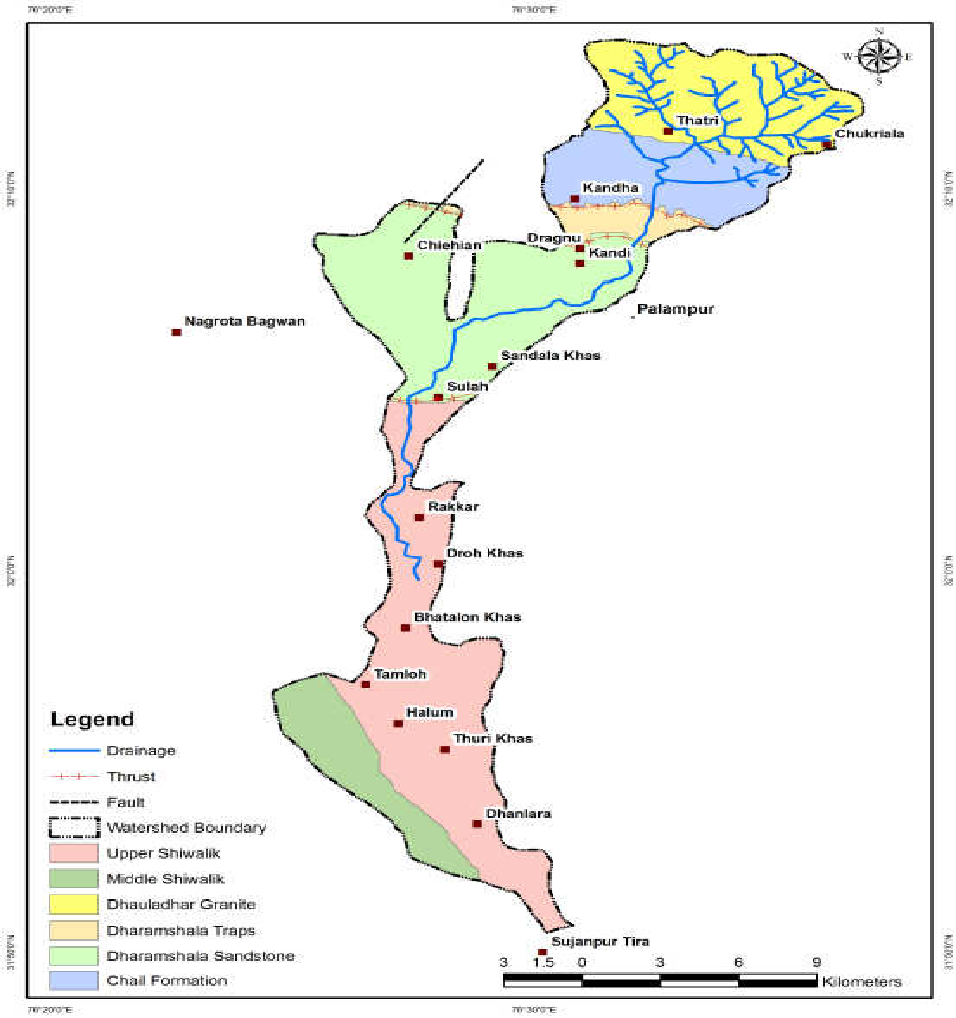

Figure 2. Geological Setting of Neugal Khad Watershed in District Kangra, Himachal Pradesh

Geomorphological Analysis

Based on the analysis of Landsat Multi Spectral Scanner (MSS) and Thematic Mapper (TM) imageries the Neugal Watershed, the area can be divided into following geomorphic regions:

1. The Permafrost Zone that covers the higher reaches of Dhauladhar Range. It has many small cirque and valley glaciers covered with glacial deposits of recent origin.

2. The Higher Mountainous Zone which lies between 3000 to 4500 m altitudes and is characterised by old valley glacial deposits and highly weathered granitic boulders. This zone also covers the periglacial features like polygon boulder fields and talus cones. Rapid weathering of the granite and gneisses has created thick cover of soil which leads to formation of grasslands and thick coniferous forest in this region.
3. The Lower Mountainous Zone lies between 1500 to 3000 m altitudes and is marked by closely associated ridges and valleys covered with valley glaciers and channels moving from North to South. The valleys are filled with glacial outwash and moraine deposits and have remnants of fluvial-glacial origin. The hill slopes have well developed soil profile of former periglacial origin. The entire zone has thick cover of coniferous forest.
4. The Piedmont Zone is a narrow zone between 1500 to 1200 m altitudes all along the base of DhaulaDhar Range. This is a landslide prone zone due to crushing of rocks along the Main Boundary Fault (MBF).
5. The Fan Zone is a long stretch of land with well marked boundaries lying between the foot of DhaulaDhar Ranges in the North and Siwaliks in the South. These are gently sloping fans with a slope of 10^0 in the north and $< 5^0$ in the middle and lower parts and mark the end point of erosional and depositional processes where the materials have been deposited at the base of mountain. An isolated ridge of Middle Siwalik rocks divides the Neugal and Baner fans at Malan locality. The Gaj, Baner and Neugal fans altogether forms a large fan which is indicative of the fact that they were the part of a former major fan system with drainage lying mainly in the Neugal area.
6. The northern part displays highly dissected molasses topography. This zone mainly comprises of upper Siwaliks conglomerates in the west while Quaternary rocks in the east. Due to fragile nature of rocks of this zone number of dissected and gullied landforms develops with deep and flat bottomed channels, filled with gravels of upper Siwaliks age. At many locations 600 to 700 m long and 200 to 300 m deep cliffs are visible around the basin as a result of neotectonic activity.
7. This zone comprises of numbers of alluvial terraces which are 3 to 60 m high and consists of boulders of granite, gneisses, and quartzite's resting on upper Siwalik rocks particularly along the Thural area. The Thural terrace lying on left bank of Neugal River is 15 km long and 2 km wide. Near the Shivnagar area the alluvial terrace comprising of gravel, pebbles and boulders embraced by brownish soils. There is a peculiar feature that all the terraces are asymmetric in character and the slope being towards the river channel.
8. Interglacial activities have been noticed almost in southern part of the Neugal watershed area and conspicuously very prominent in the vicinity of Thural area where enormous accommodation of granites and gneisses is observed. These lithological accommodations are not insitu but have been transported from long distances. Large blocks of granite and gneisses are observed scattered at many locations throughout the watershed length. Different Geomorphic Units of the Neugal Watershed are depicted in Figure 3.

Many geomorphic processes have modified the basin's surficial form by bringing physical and chemical changes. The geomorphic agents which acted as natural medium for securing and transporting the earth's material include: running water, both concentrated and non concentrated runoff, groundwater, glaciers, winds and standing water bodies to a little extent. These can further be designated as mobile agents because they remove and transport the earth material from one place and deposit somewhere else. All these agencies have originated within the basin's atmosphere and are directed by the gravitational forces, the gravity being a directional force only. All the geomorphic processes involved in the transformation of earth surface and generating typical landforms are exogenetic in nature. These processes can be defined in the following manner i.e. gradation, degradation, weathering, mass wasting, and erosion by running water, groundwater, winds; and aggradations by running water, groundwater, glaciers and human role. The results of the geomorphic analysis are shown in the Table-2.

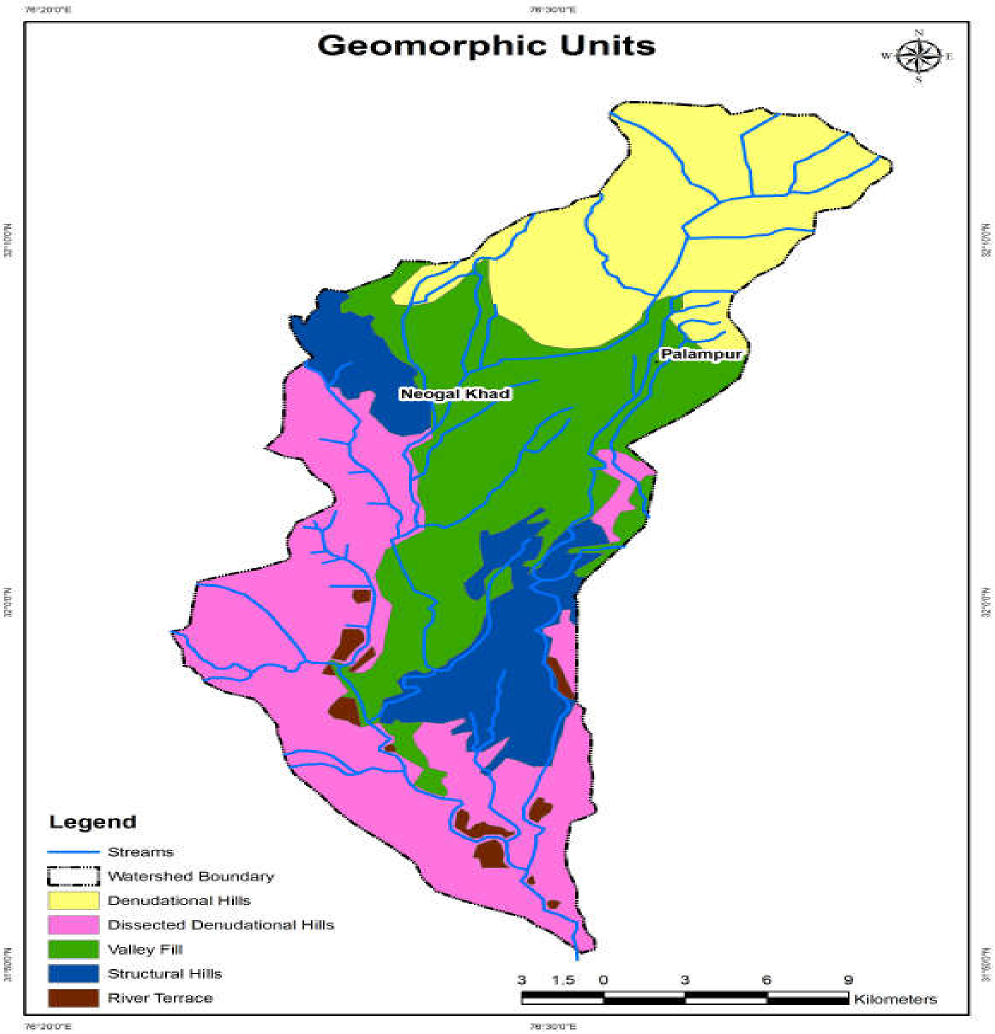

Figure 3: Different Geomorphic Units of the Neugal Watershed

Table-2: Analysis of Geomorphic units of the Neugal Watershed

Types	Area (Km^2)	Area (%)
Denudational Hills	285	26.34
Dissected Denudational Hills	246	22.75
Valley Fills	277	25.63
Structural Hills	244	22.42
River Terrace	33	3.40

Morphometric Analysis

1. Drainage Analysis

Drainage pattern can be defined as a specific plan or design which the individual stream courses form collectively. There is always a distinction between the patterns formed by the individual streams and their spacial relationship to each other. These can more specifically be defined as drainage arrangements since they define the special relationship of individual streams rather the overall pattern formed by individual drainage systems. The drainage patters in Neugal watershed reflect the impact of initial slopes, structural patterns, rock compositions and the geomorphic and tectonic history of the basin. The drainage patterns have been influenced by so many

factors which are extremely helpful in interpretation of geomorphic features and an understanding of land form and morphometric evolution of the Neugal watershed area.
The identified drainage patterns are; dendritic, trellis, barbed, rectangular, and complex out of which the dentritic pattern is most commonly observed. The frequency of the drainage is comparatively very high along the Neugal watershed area. The rivers descending down from an elevation of more than 2800 to 3500 m along the high degree of slopes and flow across the monotonous topography of the valley fill deposits of Neugal watershed. The deep gorges have been observed south of the Neugal watershed area where the rivers eroded the rocks of the upper Siwaliks. Besides, the drainage characteristics of the Neugal watershed area have also been investigated with specific reference to drainage frequency, drainage density and periodic evolution of drainage systems.
The Drainage Frequency have been calculated by using the formula

$$DF= N/A$$

Where 'DF' stands for the Drainage Frequency, 'N' is the total number of stream segments and 'A' is the aerial unit i.e. 1 sq km.
Based on this formula the following five categories of drainage frequency have been defined: (i) poor- below 4 / km^2, (ii) moderate- 4-6 / km^2, (iii) moderately high- 6-8 / km^2, (iv) high-8-10 / km^2 and (v) very high- over 10 / km^2. The observations indicate that the moderate drainage frequency is dominant along the Neugal Watershed area and spreads nearly 345 km^2 area. The details of other trends are illustrated in Table-3.

Table- 3: Drainage Frequency Analysis in the Neugal Watershed

Drainage Frequency (Length / Km^2)	Area (Km^2)	Area%
< 4 (poor drainage frequency)	242	22.34
4 -6 (moderate drainage frequency)	345	31.75
6-8 (moderately high drainage frequency)	256	23.52
8-10 (high drainage frequency)	178	16.49
Over 10 (high drainage frequency)	64	5.85

The Drainage Density was also computed using the formula

$$DD= L/A,$$

Where 'DD' is the Drainage Density; 'L' is the total stream length and 'A' is the aerial unit i.e. 1 square kilometer.
The drainage density of the Neugal watersheds is obtained by measuring the total length of stream segments in square grids with an area of one sq km. These values have been grouped into seven classes (Table 4).

Table- 4: Drainage Density Analysis in the Neugal Watershed

Drainage Density	Area (in Km^2)	Area (in %)
< 1 [extremely coarse]	25	2.34
1-2 [moderately coarse]	69	6.38
2-3 [coarse]	95	8.73
3-4 [moderate]	123	11.32
4-5 [moderately fine]	203	18.78
5-6[fine]	215	19.84
> 6 [very fine]	355	32.75

The results of the stream order analysis are presented in Table 5. The drainage characteristics of the study area revealed that the maximum frequency was of 1^{st} order streams. Further it is observed that the stream frequency decreases as the stream order increases. The densities of 1^{st} order streams are higher in the northern, southern and south-eastern part of the Neugal watershed area. This feature has however not contributed to good ground water potential in the southern part of the watersheds as the run-off and erosional processes are very pronounced which leads to higher land degradation in this region of the watershed.

Table- 5: Stream order Analysis in the Neugal Watershed

Stream orders	Area (in Km^2)	Area (in %)
1st	947	49.76
2nd	706	37.17
3rd	198	10.44
4th	51	2.63

2. Relief Analysis

Morphometry is the most popular and suitable method for the actual assessment and interpretation of relief analysis. The Neugal watershed area has been investigated in term of absolute and relative relief analysis and the results are presented in Table 6 and Table 7 respectively.

For absolute relief analysis the study area is divided into grids of one square kilometer. The maximum height of the each grid is taken as the absolute relief marked by isopleth technique. The absolute relief ranges between 450 to 2600 m and shows progressive increase from south to north of the watershed. The results indicate that the maximum area 421 km^2 and in percentage 38.83 % is occupied by the absolute relief ranging from 750-1000 m (Table 6). Major proportion of this zone is occupied by the Siwalik formations. This is highly dissected zone owing to the inter action of the orogeny and erosional factors creating variety of land forms of sharp peaks, steep peaks, steep scarps, hillocks and gorges. However, the least value is occupied by the absolute relief <500 m.

Table-6: Absolute Relief Analysis in the Neugal Watershed

Absolute Relief [m]	Area (km^2)	Area (in %)
< 500	1	0.09
500-750	182	16.85
750-1000	421	38.83
1000-1250	179	16.56
1250-1500	70	6.43
1750-2000	22	2.20
2000-2250	14	1.31
2250-2500	36	3.33
2500-1750	30	2.88
Over 2500	130	11.91

The Relative Relief (RR) analysis also carried out and it depicts difference of maximum and minimum heights of a unit. The results indicate that the maximum area 291 km^2 and in percentage 26.85 % is occupied by the relative relief ranging from 50-100 m (Table 7). It is computed by placing the difference values in 1sq.km grids. Using these values the Neugal watershed area has been divided in six isopleth groups having an interval of 125 m. The values are higher in the south, south eastern and northern part of the study area.

The relationship between absolute and relative reliefs in the study area was also carried out and it indicates that the relative relief increases with the increase in the absolute relief and shows active correlation. The value of coefficient of correlation is low for the reason that large part of the basin is still in youthful stage as a consequence of continuing neo-tectonic activity in this region.

Table-7: Relative relief Analysis in the Neugal Watershed

Relative Relief (RR) (in meters)	Area (Km^2)	Area (%)
< 25 (very Low)	145	13.25
25-50 (Low)	155	14.37
50-100 (Moderate)	291	26.85
100-200 (Moderately High)	254	23.42
200-400 (High)	133	12.38
>400 (Very High)	107	9.93

The Dissection Index (DI), which represents the ratio between relative and absolute reliefs was also calculated and it is also indicative of the erosional activities and the development of landscapes as a result of these processes.

The dissection index has been calculated for the study area by using following formula:

$$[DI] = [RR] / [AR].$$

Where DI stands for Dissection Index; RR stands for Relative Relief and AR stands for Absolute Relief.

The value of DI varies from 0 i.e. complete absence of dissection to 1 i.e. vertical cliff (Table 8). It is the degree to which the erosion has advanced or it defines the relationship between the vertical distance of the relief from the erosion level and its relative relief, i.e. the dynamic potential state of the area under investigation.

Table-8: Dissection Index Analysis in the Neugal Watershed

Dissection Index	Area in Km^2	Area in %
Less than 0.1 (Very Low)	538	49.56
0.1-0.2 (Low)	495	45.72
0.2-0.3 (Moderate)	44	4.10
0.3-0.4 (Moderately High)	7	0.68
0.4-0.5 (High)	3	0.22

Conclusion

The Neugal Watershed displays a splendid and unique example of sensitive and delicate geology encompassed with classic geomorphological features. This diverse lithology within a short span of distance makes the study area significant both tectonically and environmentally. The individual formations and groups are separated from one another by longitudinal thrust systems (following the Himalayan trend) and significant among them are the Main Boundary Thrust, Chail Thrust and the Drini Trust. Apart from these tectonic planes the area is again cross-cut by transverse faults/lineaments trending northeast-southwest. Thus the rocks are highly jointed with an average fracture density of $0.07 cm/cm^2$. The relief of study area lies above mean sea level between 800 m in the south to >2500 m in the north.The major proportion of this zone is occupied by the rocks of the Siwalik Group. This is highly dissected zone owing to the inter action of the orogeny and erosional factors creating variety of land forms of sharp peaks, steep peaks, steep scarps, hillocks and gorges. The value of coefficient of correlation is low for the reason that large part of the basin is still in youthful stage as a consequence of continuing neo-tectonic activity in this region.

Based on all morphometric parameters and geomorphological analysis; it is postulated that the erosional development of the area by the streams has progressed well beyond maturity and that lithology has had an influence in the drainage development. These studies are very useful for planning rainwater harvesting and watershed management strategies

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References

Auden, J.B., 1935. Traverses in the Himalaya. Records of Geological Survey of India 69, 123– 167.

Beaumont, C., Jamieson, R.A., Nguyen, M.H., and Lee, B., 2001. Himalayan tectonics explained by extrusion of a low-viscosity crustal channel coupled to focused surface denudation, Nature 414, 738– 742.

Dewey, J.F., and Bird, J.M., 1970. Mountain belts and new global tectonics. Journal of Geophysical Research 75, 2625– 2685.

Dewey, J.F., and Burke, K., 1973. Tibetan, Variscan and Precambrian basement reactivation: products of continental collision. Journal of Geology 81, 683–692.

Dhar, S., Randhawa, and S.S., Dhar. B.L., 2005: Geo-environmental investigations of the Baner and Neogal watersheds, Himalayan Frontal Zone, district Kangra, Himachal Pradesh, India. Environmental Geo-Hazars (Earthquakes, Landslides, Floods) : Management and Mitigation Strategy for Himachal Pradesh. In K. Sharma and M. Badoni ed. Spl. Publ. Department of Geography, K.M. College, University of Delhi.

Dhar, S., Randhawa, S.S., Sood, R.K., and Kishore, N., 2006: Lineament control and seismo-tectonic activity of the areas around Dharamsala, Himalayan Frontal. Zone, Himachal Pradesh. In P.S.Saklani 2006 (ed). Himalayas (Geological Aspects) 4th Vol. Satish Serial Publishing House, New Delhi, 73-78.

Harrison, T.M., Copeland, P., Kidd, W.S.F., and Yin, A., 1992. Raising Tibet. Science 255, 1663– 1670.

Harrison, T.M., Grove, M., Lovera, O.M., and Catlos, E.J., 1998. A model for the origin of Himalayan anatexis and inverted metamorphism. Journal of Geophysical Research 103, 27017– 27032.

Jacobs, J., and Thomas, R.J., 2004. Himalayan-type indenter-escape tectonics model for the southern part of the late Neoproterozoic-early Paleozoic East African–Antarctic. Geology 32, 721–724.

Molnar, P., England, P., and Martinod, J., 1993. Mantle dynamics, the uplift of the Tibetan Plateau, and the Indian monsoon. Review of Geophysics 31, 357– 396.

McClelland, W.C., and Gilotti, J.A., 2003. Late-stage extensional exhumation of high-pressure granulites in the Greenland Caledonides. Geology 31, 259– 262.

Nabelek, P.I., Liu, M., and Sirbescu, M.L., 2001. Thermo-rheological, shear heating model for leucogranite generation, metamorphism, and deformation during the Proterozoic Trans-Hudson orogeny, Black Hills, South Dakota. Tectonophysics 342, 371– 388.

Norlander, B.H., Whitney, D.L., Teyssier, C., and Vanderhaeghe, O.,2002. Partial melting and decompression of the Thor-Odin dome, Shuswap metamorphic core complex, Canadian Cordillera. Lithos 61, 103– 125

Pilgrim G.E., and West W.D. 1928, The structure and correlation of the Simla rocks: Memoirs of the Geological Survey of India 53, 1– 140.

Qu, G., and Zhang, J., 1994. Oblique thrust systems in the Altay orogen, China. Journal of Southeast Asian Earth Sciences 9, 277–287.

Ramstein, G., Fluteau, F., Besse, J., and Joussaume, S., 1997. Effect of orogeny, plate motion and land sea distribution on Eurasian climate change over the past 30 million years. Nature 386, 788–795.

Royden, L.H., Burchfiel, B.C., King, R.W., Wang, E., Chen, Z., Shen, F., and Liu, Y., 1997. Surface deformation and lower crustal flow in eastern Tibet. Science 276, 788–790.

Tapponnier, P., Xu, Z.Q., Roger, F., Meyer, B., Arnaud, N., Wittlinger, G., and Yang, J.S., 2001. Geology-oblique stepwise rise and growth of the Tibet plateau. Science 294, 1671– 1677.

Wadia, D.N., 1928. Geology of India, third edition. MacMillan and Co. Limited, London. 553 p.

Wentworth, C.K., 1930: A Simplified Method of Determining the Average Slope of land Surfaces, Am J. Sci. Series 5, 20p.

Yang, X., Xie, G., and Li, Z., 1992. Mylonite–migmatite lithogenic series—an important tectono-dynamic rock forming process. Geotectonica et Metallogenia 16, 151– 159.

Yin et al., (2006). Cenozoic tectonic evolution of the Himalayan orogen as constrained by along-strike variation of structural geometry, Abstract exhumation history, and foreland sedimentation. Earth-Science Reviews 76, 1 –131

Yin, A., Rumelhart, P.E., Butler, R., Cowgill, E., Harrison, T.M., Foster, D.A., Ingersoll, R.V., Zhang, Q., Zhou, X.Q., Wang, X.F., Hanson, A., and Raza, A., 2002. Tectonic history of the Altyn Tagh fault system in northern Tibet inferred from Cenozoic sedimentation. Geological Society of America Bulletin 114, 1257–1295.