Summary and Conclusion
SUMMARY AND CONCLUSION

One of the potential, yet underdeveloped applications of digital remote sensing data is for geomorphological study and landscape interpretation. Digital elevation and remote sensing data sets contain different, but complementary information related to geomorphological and geological features. Digital elevation models (DEMs) represent the topographic information of land surface whereas remote sensing data record the reflectance/emittance of different features or spectral characteristics of surfaces. Computer analysis of integrated digital data sets can be exploited for geomorphological classification and geological studies using automated methods developed in the remote sensing community. The landscape change and process-based studies in digital earth sciences require the excessive use of DEM as DEM not only provides the description about three-dimensional surface and data foundation for impressive three-dimensional visualization of geographical data but also sets the foundation for deriving other surface morphological parameters such as elevations, slope, aspect, curvature, slope profile and catchment areas.

The present study focuses on the mapping of lithological and geomorphological units, structural elements and morphometric analysis of Sitla Rao watershed using remote sensing data. The identification and classification of landforms is carried out on the basis of overall appearance (morphography), shape/surface geology (morphometry), relief forming processes and association of forms. The study focuses on the comparison of certain terrain attributes such as elevation, slope and aspect obtained from the DEMs generated from toposheet, SRTM and ASTER.

The intermontane basins of Himalayas are very important areas for morphotectonic studies. Different phases of Himalayan upheaval, neotectonic movements are very well imprinted in the landforms, developed by denudational and tectonic processes. The importance of the analysis of geological and geomorphological features of such intermontane basins increases particularly when they are located between active faults and thrust and intersected by transverse
lineaments. The Doon valley is one such synclinal depression between Lesser Himalayan mountain in north and Sub-Himalayan Siwalik in south. The geological studies of the Lesser Himalayas appear to be peculiar and unique because of close associations of Tertiary and Pre-Tertiary rocks at a short distance. Proterozoic to Lower Cambrian rocks of Lesser Himalaya are separated from the Cenozoic Siwalik Group and Doon gravels by the Main Boundary Thrust. This NE dipping tectonic feature, brings Krol Group of rocks to override the Siwalik. In the study area, Middle Siwalik is dominated by friable grey colored sandstone and Upper Siwalik is represented by Boulder Conglomerate Formation dominated by the Pre-Tertiary clast derived from the Lesser Himalaya. Phyllite and quartzite belonging to the Krol Group override Upper Siwalik boulder bed near Koti Nadi, Chandpur. Aliened parallel to the general trend of Himalaya, the study area forms an intermontane valley, the bottom of which is filled with the thick colluvial deposit of numerous short, shallow and bouldery streams, brought from overlooking hill slopes. In central part, the Siwaliks are completely masked by ~300m of thick Doon gravel whereas the Upper and Middle Siwalik Formations are exposed in the southern slope with gentle dips. Doon gravel mainly consists of thick soil, boulder and pebble interbedded with clay categorized into Unit A, B and C on the basis of lithology and structural framework. Sub-montane soils of the region are derived from sandstone and shales. Unit-A characterized by poorly consolidated gravel bed with sub-angular to sub-rounded, granular to pebble size clast, embedded in fine grained matrix and interlayered with sand and mudstone. Lithologically Unit-B is characterized by unconsolidated poorly sorted clast, supported massive gravel with predominance of rounded to sub-rounded boulders and pebbles predominantly of quartzite together with sandstone and phyllite. Younger fan surfaces, composed of poorly sorted, angular to sub-angular granule and pebbles, interspread with large pebbles and occasionally boulders supported by finer clast is categorized as Unit-C.

The role of geomorphological studies is of great significance in the classification and evolution of various landforms developed in a basin. Based on the image characteristic and terrain features of different landforms, hills, piedmont,
valleys, side slope and alluvial plain are delineated. The results showed that the watershed is occupied with diverse terrain characteristic in north and alluvial plain in south with sloppy terrain. Further study shows that river terrace deposits occurring as an isolated patch while doon fan gravel terrace are found in the central area along the river. These river terraces are composed of gravels, pebbles, boulders, sand, clay and rock fragments and formed by erosional work of streams flowing down from the Lesser Himalaya. The southern slope of Lesser Himalaya is characterized by a number of alluvial fans forming low lying doon fan gravel dissected hills having variable slope. On either side of the Asan River sub recent fan terraces are very much conspicuous and maintain a bit higher elevation from valley floor of recent alluvium. This unit is of sub-recent in age and comprises boulders, gravels, pebbles, sand and clay. Moderately dissected structural hills are found in Lesser Himalayan region in northern portion of the study area. The upliftment along the MBT reoriented drainage ridge lines show development of steeper slopes in the north. Presence of compact, massive, medium to coarse grained friable sandstone favors moderate dissection in this zone. The piedmont zone extends from the Siwalik water divide in the south and extends up to synclinal axis of the Doon valley in the north. The piedmont zone mainly consists of the assemblages of boulder, gravel, clay and pebbles. In the study area, river terraces are relics of former flood plain levels that have undergone cyclic uplift and subsequent erosion. The sediment matrix of terrace consists of clay, silt, sand, gravel, pebbles and boulders. Since the river in the study area flow through unconsolidated materials like boulders, pebbles, sand, silt and clay, results in the development of channel bars, which is the youngest geomorphological unit, located around the rivers viz; Asan, Sitla Rao, Mauti Nadi, Koti Nadi, Gauna Nadi and Chor Khala.

The supervised digital classification of ASTER image for various landuse/landcover categories shows that doon gravel (Unit A-C) geomorphologically represented by sub recent fan terrace, river terrace, piedmont dissected slope. Doon fan gravel terrace is completely occupied by the population and is extensively cultivated whereas Doon valley is covered by doon fans which have long slopes.
having urban and agriculture land use. The doon fans have patches of forest, indicating original ecological conditions modified by human settlements. Moderately dissected hill and some part of doon fan gravel terrace which represent doon gravel belongs to Middle and Upper Siwalik, covered thick vegetation and occupied by dense and moderately dense forest. The rugged terrain at slightly higher level and Lesser Himalaya representing moderately dissected structural hills which are either rocky land or covered by dense forest. Unlike Siwalik Hills, Lesser Himalayan dissected hill have steeper slope and higher relief characterized by rocky barren land.

The various types of drainage patterns observed in the study area having profound control of bedrock geology. In the Lesser Himalayan parts which have heterogeneous bedrock, the pattern tends to be dendritic to sub-dendritic, whereas in homogeneous lithology with gentle slope, the drainage pattern is parallel. Dendro-trellis to trellis pattern is also observed in some areas which indicate parallel faults or lineaments. Digital elevation model of Sitla Rao watershed indicates the upliftment of watershed in the northern region, resulted in the reorientation and modification of structural and drainage elements of the watershed. The present study reveals that second order stream joins to form one third order streams and no fourth order stream is found in Jagatpur and Abdullahpur micro-watersheds, unlike other micro-watersheds calculated from the ASTER data, shows that some geological factors prevent to join lower order streams which form higher order stream. The Rb value ranges between 3.16 and 6.14 which are slightly higher than the range (3-5) indicates the possibilities of geological control over drainage pattern. Further, high Rb values obtained from ASTER as compared to that of toposheet gives better idea regarding geological disturbance in the study area.

Usually micro-watersheds follow the general trend of maximum total length of stream segment for first order, which decreases in length with the increase of stream order. However, stream lengths obtained from toposheet for Rudarpur micro-watershed do not follow this trend which may be due to moderately steep slope, flow of stream from high altitude, change in lithology and probable uplift across the micro-watershed.
The mean stream length values indicates that Rudarpur, Jagatpur and Abdullahpur micro-watersheds have variation in second and third order stream, obtained from toposheet, while the ASTER data show variation in third and fourth order streams in Chhorba micro-watershed and second and third order stream segment in Abdullahpur micro-watershed. Both the data show variation in Abdullahpur micro-watershed, clearly indicates variation in topographic elevation and slope of this micro-watershed. This is also in accordance with the stream length values which indicate same variation in topography and youthful stage of geomorphic development. ASTER data show stream length ratio high in almost all the micro-watersheds, indicating their upstream location where the rocks are highly competent and impermeable.

Out of the total area 183 km$^2$ of the Sitla Rao watershed, Rudarpur micro-watershed occupies the maximum whereas Abdullahpur micro-watershed occupies minimum. Low values of elongation ratio in Dobri, Chandpur and Jagatpur micro-watersheds indicate elongated shape and tectonic control on the stream development. Although all the micro-watersheds are of elongated shape except Chhorba micro-watershed which is less elongated. The high value of circularity ratio in Chhorba and Rudarpur micro-watershed indicates homogenous geological material, whereas least value of circularity ratio in Dobri micro-watershed indicates high to moderate relief and structurally controlled drainage system. Further, Dobri micro-watershed has the lowest values of form factor, since it is long and narrow while Chhorba micro-watershed has the maximum value since it is least elongated. The drainage density in the study area is low and varies between 0.68 and 1.52 km/km$^2$ (toposheet) and between 1.13 and 1.69 km/km$^2$ (ASTER). Jagatpur micro-watershed has minimum drainage density value obtained from ASTER data and second minimum value from toposheet, suggests that the region has highly permeable subsurface and dense vegetation cover with low relief. The higher values obtained from ASTER data suggest increase in dissection over time which is possibly due to anthropogenic activities. The highest stream frequency in the Dobri micro-watershed of the upper reaches attest to the existence at resistant but dissected bed rock in the lower zone of
Asan river. Jagatpur micro-watershed has minimum values of infiltration number obtained from ASTER data and second minimum value from toposheet, indicates infiltration in the micro-watershed, attesting to permeability of underlying material. The maximum infiltration number obtained from both the data in Dobri micro-watershed, indicate the presence of impermeable bedrock which is also in accordance with the presence of moderately dissected structural hill in this micro-watershed. The Rudarpur micro-watershed shows moderate drainage texture whereas other micro-watersheds show coarse drainage texture, suggesting massive and resistant bed rock in these micro-watersheds. However both the data indicate moderate texture in Dobri micro-watershed. The length of overland flow from toposheet in Dobri and Chandpur micro-watersheds possibly suggest high drainage density in these micro-watersheds as compare to ASTER whereas higher values are obtained in Rudarpur, Chhorba and Chandpur micro-watersheds.

The relief ratio suggests least slope in Chandpur micro-watershed due to its location in valley floor whereas high relief in Dobri micro-watershed suggest steep slope in this micro-watershed. Further high values of relief ratio are characteristic of hill region and low values are characteristic of pediplain and valley. The variable ruggedness number indicates variation in elevation in different micro-watersheds. The values obtained from ASTER data are higher than that obtained form toposheet but are comparable. However, in both toposheet and ASTER indicates highest relief in Dobri micro-watershed. Dobri micro-watershed also has highest drainage density, as such high values are expected in mountainous region of tropical climate with high rainfall.

Among the morphological parameters elevation, relief, slope and aspect have been arguably the most frequently utilized in GIS applications. In the present study comparison of the minimum elevation, maximum elevation, mean elevation, relief, slope, aspect and standard deviation of various geomorphological units and different micro-watersheds obtained from ASTER-DEM, SRTM-DEM and DEM derived from the toposheet were compared. The comparative study show that moderately dissected structural hill has the highest elevation and relief while the piedmont dissected slope
has the lowest elevation in all the cases of DEMs. Steep slope is being encountered in moderately dissected structural hill (geomorphological unit) and lowest in piedmont dissected slope. Further analysis shows that the aspect values obtained from SRTM-DEM and Toposheet-DEM are almost same for every geomorphological unit in all the micro-watershed. Elevation and relief analysis showed that the Dobri micro-watershed has the highest value of these parameters in all the cases of DEMs. However mean elevation, slope and relief are lowest in Chhorba micro-watershed where piedmont dissected slope is found.

The present work gives a detailed idea about the geological and geomorphological condition of Sitla Rao watershed and its effects on the landuse/landcover pattern. Complexity of terrain is clearly brought out through the investigation and particular landuse/landcover categories are identified for each geomorphological unit. Complete morphometric and DEM analysis of different micro-watersheds suggest that Dobri micro-watershed is characterized by hilly terrain and mountainous region. The study also reveals that the region is occupied by moderately dissected structural hill of Lesser Himalaya due to which the region is either barren or occupied by forest where the soil had chance to develop. No landuse category is identified in the region. The mean elevation and relief of the Dobri micro-watershed is the highest among all the micro-watersheds as moderately dissected structural hill which falls in this micro-watershed shows the highest mean elevation and relief.

The study also reveals that the analysis of terrain features by remote sensing and GIS is affected by the resolution of digital elevation model. In most rugged terrain of moderately dissected structural hill which falls in Dobri micro-watershed and elevated doon fan gravel dissected hill which mainly occupies Abdullahpur micro-watershed, the terrain features are more clearly visible in statistical analysis of ASTER-DEM than other low resolution DEM. This demonstrates that as resolution becomes finer, more accurate and variable results are obtain than that given by a coarser resolution. Since the region is tectonically active, the study gives a data base for the landuse planning and management.