SUMMARY AND CONCLUSION

The degradation of geomorphic environment is a process of hydrothermal and geothermal reactions in the landscape, which compels the elements and minerals to migrate. Such migration of elements and minerals in the environment receive energy from solar radiation, geothermal activities and gravitational forces. These processes have direct effect on the geomorphological processes, which are responsible for the landscape sculpturing. Any element or mineral which migrates in the environment ultimately comes in the water, because rivers are the best vehicle for their transportation, particularly in a humid region. The rivers contribute 89% of the total sediment flux transfer to the oceans. This comes from the processes of weathering and erosion operating with the varying intensity in different parts of the river catchment. Therefore, the study of nature and amount of sediment carried by a river becomes an indispensible tool in understanding the processes of environmental degradation in the river basin.

The Dhauliganga basin situated in the alpine environment of greater Himalaya has been chosen as basic unit for the present study. The Dhauliganga river originates from the glacier Kamet, situated in the Zanskar range of greater Himalaya. The main stream of the river which
comes from Dhaulagiri glacier called Ganeshganga in its infant stage. The Dhaulaganga has developed a 6th order basin in Strahler's hierarchy of stream ordering, on the left bank of Alaknanda river. It forms an unique shaped basin over an area of 1992 km², near the China border on the transitional area of Garhwal and Kumaon regions of Central Himalaya. Geographically, basin extends from 79°30' E to 80°15'E longitude and 30°15'N to 30°45'N latitude. Administratively, basin covers an area of Chamoli district of Garhwal and some part of Pithoragarh district of Kumaon region, in extreme north of Uttar Pradesh.

The underlying lithology of the basin has been divided into two formations by Dhar Martoli fault. In the west of the fault are metamorphic formations; the rocks of which are mica schists with quartzite layers, alternating with real biotite gneiss which becomes predominant towards Joshimath. In the east of fault sedimentary formation of Tethys zone is prevailing, dominated by limestone.

The absolute relief of the basin varies from 1460 metres lowest (Vishnuprayag) to 7817 metres highest (Nandadevi). Maximum area of the basin (1409 km²) lies in between the absolute height of 4000 to 6000 metres, which is an indicator of youthful stage of the present
study basin. The relative relief of the basin has a great degree of variation ranging from 80 metres lowest to 1640 metres highest. It indicates the development of deep valleys and escarpments. Similar facts have been established by the dissection index analysis, which ranges from 0 to 0.40 in the basin, that the rivers have developed steep escarpments and gorges due to the deep downward cutting by the antecedent drainage.

The average slope of the basin ranges between 27.5° (maximum) to 0.7° (minimum). Maximum area of the basin lies in moderately steep slope zone (10°-25°), which covers 66% of the entire basin, indicating the early stage of cycle of erosion. Other statistical measures of the slope distribution indicate the initial stage of the slope development in the basin. The development of average slope in the basin is a resultant of combination of hydrological, topographical and geological factors viz. drainage density, stream frequency, relative relief, absolute relief, dissection index and underlying lithology.

The extreme high stream frequency and drainage density of the basin with high absolute and relative relief indicate the youthful stage of the basin development, whereas deep river valleys show the continuous upliftment. The detail study of drainage density development in the basin shows that the geomorphic parameters have their significant
control over the drainage density development in relation to the underlying lithology. The results of correlation matrix show that the development of drainage density is a combined function of absolute relief, relative relief, average slope and dissection index.

The Dhauliganga is a glacial fed river, which receives water from Kamet glacier, Nandadevi glaciers, Rishi glaciers, Trishul glacier and Kosa glacier etc. Therefore, river receives its maximum discharge in the ice melting season. Around 77% of the total annual discharge is recorded during the period of five months between May and September. The seasonal and spatial fluctuations of the hydrological regime of the river are influenced by the rainfall conditions of the basin. Girthiganga in upper part and Rishiganga in mid stream region are important tributaries, which significantly contribute to its discharge. Rishiganga alone contributes 25% of the total discharge at Tapoban site.

The pH of Dhauliganga basin ranges from 7.67 (average) in summer season to 8.25 (average) in monsoon season. This shows the more chemically active nature of the river. Alkalinity shows a fluctuating but increasing trend downstream and is significantly influenced by the confluence of tributaries. The specific conductivity of the water samples ranges from 140μs/cm to 270μs/cm in summer.
season and 97 μs/cm to 281 μs/cm in monsoon season. No
definite trend has been noticed in specific conductivity
distance downstream. However, a control of tributaries
has been observed. The total dissolved salts (annual)
range from 82.95 ppm to 192.85 ppm. \( \text{HCO}_3^- \) and \( \text{Ca}^{++} \) are
two major constituents of river water containing 45.61%
and 14.11% by weight of TDS, respectively. Another most
abundant dissolved species are \( \text{SO}_4^{--} \) 14.97%, \( \text{Cl}^- \) 6.78%,
\( \text{Na}^+ \) 2.29% and \( \text{PO}_4^{---} \) 1.31% of TDS. Rest are \( \text{SiO}_2 \) 5.46%,
\( \text{K}^+ \) 0.98%, \( \text{NO}_3^{-} \) 0.88% and \( \text{Mg}^{++} \) 0.51% of TDS. \( \text{HCO}_3^- \) constitutes
65.58% of anions and \( \text{Ca}^{++}+\text{Mg}^{++} \) constitute 81.72% of cations
on equivalent basis. These results are comparable to
other Indian and world rivers. The TDS value for summer
season is lowest at Kailashpur (98 ppm) but higher than
TSM indicating domination of chemical weathering in the
upper part of the basin. Girthiganga brings highest TDS
(189 ppm) and enhance the TDS concentration in the trunk
stream. Similar pattern has been noticed in the monsoon
season with higher TDS flux from Girthiganga (196.7 ppm)
catchment.

The TSM values for the Dhauliganga for summer season
show an increasing tendency mouthward. The highest TSM
value (620 ppm) has been measured for Girthiganga, which
drains over the sedimentary rocks formation of Tethys zone.
While Rishiganga brings very low TSM (72 ppm), which decreases the TSM value of trunk stream. In monsoon season contrary to summer season Girthiganga brings low amount of TSM and Rishiganga brings very high amount of TSM (264 ppm). These two tributaries control the TSM of trunk stream accordingly.

The most abundant clay mineral in the suspended sediment of Dhauli ganga is illite (8.61%), followed by Kaolinite (2.86%) and Chlorite (2.60%). Montmorillonite (1.85%) is also present but only in the central and lower parts of the basin. Quartz and feldspar are the most abundant detrital minerals in the suspended sediment. On an average quartz is 59.42%, while feldspar is estimated 12.91%. Calcite and dolomite are important carbonate minerals. Dolomite is estimated to be 2.15% in the suspended sediment and calcite 8.88% on an average. Plagioclase is estimated to be 0.65% and amphibole is noticed in traces on few locations.

The grain size analysis of bed sediment shows that the distribution of grain size in the river course is governed by the environmental conditions of the catchment. The average mean size of the grain in Dhauli ganga basin is 0.62 $\bar{\phi}$ (620 micron). Maximum mean size of sediment has been observed at Hotspring site, which is -0.68 $\bar{\phi}$ (1680 micron) and minimum at Reni site in Rishiganga i.e.
1.45 Ø (325 micron). The present study does not prove the general hypothesis that the bed material becomes finer and more uniform in downstream direction. The sorting index of the bed sediment size distribution reflects the consistency in the energy level of the depositional environment. The average value of sorting index for the whole basin is 1.47 Ø, which indicates the poorly sorted depositional activities of the drainage. Maximum values of skewness for the main channel have been observed negative ranging from -0.45 to -0.04 minimum. This reveals the fact of high energy conditions and heterogeneous and coarse sediment deposition by the river. The kurtosis index for the entire basin standing at 1.37 indicates leptokurtic (peaked) distribution of sediment grains. The maximum peaked nature of distribution observed in the upper part (Kailashpur, 2.32) of the basin, indicates the more intense sorting of the central part of distribution, while low value in lower part (Bilagarh, 0.74) reveals the more intense sorting of the tails than the central part of the grain size distribution. The deposition of sediment between Markura and Suraithota on an average 48.87% are in boulder form, 7.42% in gravels and cobbles form, 5.07% coarser sands, 11.92% medium sands, 15.54% in fine sands and rest 5.86% are silt deposits. In central part of the basin this composition changes abruptly after the confluence of Rishiganga. At Hotspring site 68.32%
sediment in boulders form, 15.04% in the gravels and cobbles size, 2.78% coarse sands, 5.5% medium sands, 5.79% fine sands and rest 2.57% are silt deposits.

The minerological composition of bed sediment shows that quartz is the most abundant mineral, containing 65.76% on an average. This is because of domination of mechanical weathering in the metamorphic rocks of the central crystalline particularly by the process of thawing and freezing. Followed by calcite 11.01%, illite 2.47-19.9%, feldspar 6.28%, dolomite 1.56-24.4%, kaolinite 0.64%, montmorillonite 1.12%, chlorite 0.44%, plagioclase 0.89% and amphibole on few locations.

The total sediment load at Markura (the upper most site) has been estimated 421830 tonnes/yr. Out of this 252560 tonnes/yr is suspended sediment and rest 169270 tonnes/yr is dissolved load. Sediment load of Reni site, 17 kms below Markura site is estimated to be 459370 tonnes/yr (265720 tonnes/yr suspended sediment and 193650 tonnes/yr dissolved load). Rishiganga, the most important tributary of the Dhauliganga discharges a total flux of 288140 tonnes/yr. Out of this total flux 104010 tonnes/yr are dissolved solids and rest 184130 tonnes/yr are suspended matters. The total sediment load at lower most site Tapoban is estimated at 1244190 tonnes/yr, out of this 727360 tonnes/yr are suspended matters and 516830 tonnes/yr are dissolved solids. Maximum sediment flux
in the basin is received in five months (May to September) of the year.

Gross loss of individual element has been estimated at four important sites in the catchment. At Markura site bicarbonate constitutes 44.55% (71596.80 tonnes/yr\(^{-1}\)) of TDS, followed by calcium 14.78% (23754.55 tonnes/yr\(^{-1}\)), sulphate 13.44% (21596.37 tonnes/yr\(^{-1}\)), silica 6.17%, chloride 6.08% and sodium 1.84% etc. This composition changes at Reni site, where bicarbonate constitutes 40.93% (78787.16 tonnes/yr\(^{-1}\)) of the TDS, followed by calcium 17.06% (32842.13 tonnes/yr\(^{-1}\)), sulphate 13.03% (10523.06 tonnes/yr\(^{-1}\)), silica 5.47%, chloride 4.96%, sodium 2.16%, phosphate 2.12% but contribution of nitrate is considerably high which is 1.98% of the TDS. The gross loss composition of individual element in TDS of Rishiganga is different from Dhaliganga, where bicarbonate shares 32.74% (33831.11 to tonnes/yr\(^{-1}\)) of TDS. In contrary to the mentioned two sites, sulphate emerges as the second highest contributor 17.66% (18250.28 tonnes/yr\(^{-1}\)), followed by calcium 13.02% (13456.17 tonnes/yr\(^{-1}\)). The contribution of chloride (9.8%) is higher than the silica (7.59%), followed by sodium. At the lowest site Tapoban, bicarbonate is again highest shareholder 44.83% (230549.67 tonnes/yr\(^{-1}\)) of TDS. Followed by calcium 13.78%, sulphate 12.60%, silica 5.44% and sodium 3.02%, the share of chloride is very low 1.73%, in relation to other sites.
The loss rate of element increases downstream for all elements excluding chloride. The highest rate of loss has been estimated for \( \text{HCO}_3^- \) which is 124.08 tonnes/km\(^2\)/yr for the whole catchment. This is followed by \( \text{Ca}^{++} \) 38.13 tonnes/km\(^2\)/yr. The rate of \( \text{Cl}^- \) is only 4.78 tonnes/km\(^2\)/yr at Tapoban, while Rishiganga catchment decomposes 14.75 tonnes/km\(^2\)/yr. Sulphate is another important element in the Dhauliganga environment, which has third highest rate of loss 34.88 tonnes/km\(^2\)/yr for the whole basin. Followed by silica 15.06 tonnes/km\(^2\)/yr, \( \text{Na}^+ \) 8.36 tonnes/km\(^2\)/yr, \( \text{NO}_3^- \), \( \text{K}^+ \), \( \text{PO}_4^{---} \) and \( \text{Mg}^{++} \). The rate of element loss is 18 times higher than the W5 experimental watershed and almost 3 times higher than W2 deforested watershed. This is an indication of very high rate of decay in the landforms of the basin.

The total rate of erosion for the entire Dhauliganga basin at Tapoban site is estimated 669.64 tonnes/km\(^2\)/yr. Out of which 391.47 tonnes/km\(^2\)/yr is due to the physical erosion and rest 278.16 tonnes/km\(^2\)/yr due to chemical erosion. This is higher than the whole Ganges catchment and double of Yamuna's rate of erosion at Allahabad. Physical erosion is dominated in the whole basin. The rate of erosion increases with the increase in the basin area and there is a positive relationship between physical and chemical erosion rates. Basin elevation is also an important controlling factor but only in support of the
The rate of lowering of the basin increases stream downward. It is estimated at 0.87 mm/yr at the upper most site Markura (0.18 mm/yr due to chemical erosion and 0.69 mm/yr due to mechanical erosion). The lowering rate of Rishiganga is estimated to be 0.82 mm/yr (0.15 mm/yr due to chemical erosion and 0.67 mm/yr due to mechanical erosion). The lowering rate of the basin as a whole at Tapoban site is 1.26 mm/yr (0.28 mm/yr due to chemical erosion and 0.98 mm/yr due to mechanical erosion).

The present study in the last recommends certain precautionary measures viz. social acceptability, prevention of debris slide on the slopes, erosion control by coir netting, slope treatment by asphalt mulch technique of vegetation turfing, construction of retaining and sausage walls, ban on blasting, not to remove base boulders, ban on cattle herding in Bugyals and change in agronomic practices for the preservation, conservation and regeneration of the environment in Dhauliganga basin.