SUMMARY

Snow is highly reflective, unstable and porous material, which is composed of frozen water (ice) and air. It undergoes constant change due to ambient conditions and becomes essential matter in earth’s climate system because large areas of Himalaya covered with seasonal snow. On earth’s surface Himalaya is the assemblage of biotic and abiotic components, which has direct concern with ecology and the sensitivity of the earth’s climate, hydrological as well as ecological system depends on land cover changes. This gives immense importance to study the topographic influence on snow physical parameters especially when satellite data provides timely and efficient information about large land area. But in optical remote sensing image, the Irregular shape of terrain causes variable illumination angles and diverse reflectance values within same land cover. It causes problems in image segmentation and misclassification (snow with other land cover. This perception leads to carry forward the research by setting objectives of the thesis in the field of topographic correction and its influence on snow physical parameters.

Initially in the present work an empirical-statistical based topographic correction (ES$_b$TC) algorithm has been developed for reflectance modeling after comparing with existed topographic correction methods like Cosine correction, C-correction, Minnaert correction, sun–canopy–senor with c-correction (SCS+C) and slope matching for AWiFS and MODIS images. The results has been analyzed based on qualitative (visual), quantitative, graphical analysis and in-situ observation. Results from (i) Visual analysis (Figure 19, 20,21 and 22) suggests that ES$_b$TC method is most suitable than slope matching methods where as other methods are not suitable for Himalayan terrain especially with varying altitude from 1100m to 8000m. (ii) Quantitative analysis results from (Table 10) i.e. on comparing snow spectral reflectance on north and south aspect of entire image display the weightage of ES$_b$TC algorithm than other topographic algorithms as mentioned above. (iii) Graphical analysis (Figure 24 and Table 11) also satisfies the topographic correction condition for the method and validates suitability for Himalayan region. (iv)Field results for model validation are more prominently matched for ES$_b$TC algorithms, for slope match method it is slightly matched where as it fails for all the other methods. Study reveals that the cosine correction, C-correction, Minnaert correction, SCS+C correction not very successful for Himalayan terrain and produce poor results. These methods
show completely non-Lambertian behaviour of the Himalayan terrain. Hence it is concluded that the all above discussed models are just satisfying only one or two criteria of their performance. No doubt slope matching methods is satisfying all the criteria of topographic correction but ESbTC model satisfies the same criteria with better efficiency than slope matching. Thus ESbTC model is found to be a unique and most suitable algorithm for Himalayan terrain with varying solar geometry and varying altitude from 1100 m to 8000m for qualitative and quantitative analysis of snow cover.

Next issue in the present study was snow cover mapping. In the present work qualitative and quantitative comparative analysis of various statistical models for snow cover mapping on AWiFS, MODIS and Hyperion satellite data for different ranges of Himalaya is reported. Investigation suggests the advantages and limitation of NDSI over S3 and NDSII index for snow cover mapping in Himalaya. Results suggests that NDSI as a complex method for snow cover estimation in shadow areas even after applying topographic correction and for water body NDSI has high positive values which merges with snow cover area and require additional exercise for snow cover mapping. S3 model is only suitable for low altitude to identify snow under vegetation without using references data, while NDSI and NDSII both need vegetation data to identified snow area under dense vegetation. To overcome these gaps a new band ratio algorithm called Weighted Normalized Difference Snow Index (WNDSI) is reported which provides useful information in characterizing snow cover and enhance snow cover mapping with auto water masking technique. Performances of all these methods were validated with an existed statistical classification technique SAM, MLH and SVM and notice the shady areas in all ranges of Himalayas are unclassified with SAM technique (Figure 39). On the other hand MLH techniques over/less estimate snow cover area whereas the appearance of different land covers using SVM (Table 13 (a-c)) are quite similar with WNDSI model. Figure 38, Figure 39 and Figure 40 shows the thematic results of snow and non-snow area. Study reveals that percentage snow cover area estimated by WNDSI is approximately equal to the snow area estimated by SVM sub-pixel technique for all ranges of Himalaya (Tables 13(a-c)) with low RMSE value (Table 14).

Various field experiments has been carried out at the time of satellite passes in the field (over the study area) as well as in avalanche prone area to understand the influence of surface parameters (snow, snow classes (dry, moist, wet), soil, vegetation, water, contaminated snow, snow under shadow, avalanche snow under shadow, soil contamination, grain size, ageing and
slope/aspect) on spectral reflectance with spectroradiometer in the wavelength range 350–2500 nm. These field results are further used for model validation estimated for AWiFS, MODIS and Hyperion imagery after atmospheric and topographic corrections.

Topographic influence on snow physical parameters such as snow surface temperature, snow grain size, snow classes, albedo and snow cover area was the further topic of investigation in the present study. Results indicate the spatial patterns of snow temperature gradients are strongly influenced by topographic variables over the course of a single snow season (Figure 44). While terrain is certainly an important consideration, static topographic effects alone cannot account for the spatial variation seen in snow temperature gradients. Dynamic factors, such as changing weather (Figure 45 and Figure 51) are critically important. A qualitative analysis of weather data collected indicates that spatially observed time series of weather parameters could be important components in future models. It has also been observed that fine grains are found to be in snow accumulation area whereas medium/coarse grains are at ablation /lower elevation areas. Medium/coarse grains comprise the presence of moist snow in an area that indicates the faster melting whereas dry snow composed in area will melt slightly later as compared to other snow classes. Study further analyzed the spatial and temporal variations of mean albedo of snow in satellite data at different altitude zones. The complete study area was divided in different altitude zones from 2000 to 5600m at an interval of 600m. An evaluation of the results of temporal variations means albedo of spatially distributed snow in Figure 48 reveals regional patterns related to variations of snow cover type along the altitudinal transect. This confirms that albedo analysis may be used to estimate onset of melt at regional scale. The results of snow line elevation of Beas catchment area in the month of peak winter (January and February) of year 2013 indicates the slightly higher trend than the previous year (Figure 56). Whereas zonal wise study (LHZ, MHZ and UHZ) on the trend and variability in areal extent of snow cover of North-West Himalaya from year 2000 to 2013 alarming the decreasing trend of SCA in lower and middle Himalayan zone (Figure 59 and Figure 60). This is due to the trend of meteorological parameters with enhanced warming trend in a past decade (Figure 62). A study on snow cover monitoring from year 2000 to 2013 indicates that such a decreasing trend in SCA in LHZ and MHZ due to local regional climate variations can threaten the storage efficiencies for many reservoirs. This has great impact on a reliable management of the water resources for power generation and irrigation.
Present study also has given immense importance to study the land cover classification and change detection analysis in snow bound region as a part of remote sensing application on satellite imagery of North-West Himalaya. Hyperion classification results from Figure 63 and Table 16 shows that the SAM and MLH methods are not very successful in classifying Himalayan regions and produce poor results. Mostly the shady areas in all ranges of Himalayas are unclassified with SAM technique. Extracted land surface parameters using SVM are quite similar in texture and areas on comparing with existed models. In few places, using SVM there is a small deviation which may be due to the selection of threshold values used for the conversion of indices to surface classes. It is important to note that the threshold values are likely to be scene dependent and empirical analysis may be necessary for each case. Hence the study reveals the suitability of SVM model for change detection analysis using Hyperion data. On the other hand a spectral change vector analysis method tested for detecting change in images between two dates for AWiFS and MODIS images. The inferences drawn from Figure 64, Figure 65 and Table 17 can help a forecaster in assessing the avalanche danger. The avalanche occurrence information system can enable a forecaster to further improve his avalanche forecasting models. High temporal resolution of satellite imageries can also help in improving avalanche occurrence information system i.e. site specific.

Hence overall results conclude that topographic corrections especially for Himalayan terrain in optical remote sensing are very useful for further applications such as sub-pixel snow mapping, energy balance studies, climatic modeling, ecological studies, snow melt run-off modeling, change detection analysis and for avalanche hazard analysis.

FUTURE SCOPE

The research can be focused on the entire Himalaya to check the suitability of empirical-statistical based topographic correction algorithm (ES<sub>8</sub>TC) model with different periods of satellite images as well as with different satellite sensor. The research can be further extended on global basis to derive guidelines, which method performs best under which situation. So that Himalayan cryosphere can understand with better understanding.