List of Figures

Figure 1.1 Landslide hazard zonation map of India (NDMA 2009). .........................6

Figure 2.1 Geographical location map of the study area, (a) Map of India showing Uttarakhand state (b) Map of Uttarakhand state showing location of Chamoli district and (c) ASTER DEM showing study area (Inside brown colour boundary) along with National highway-58 corridor and Alaknanda river traverse in the area. .................................................................11

Figure 2.2 TRMM 2b31 minimum and maximum rainfall in the study area obtained by monthly averaged from 1998 to 2010 (Bookhagen and Burbank 2010). .................................................................................................................................12

Figure 2.3 Major tributaries and drainage map of Alaknanda river in study area....14

Figure 3.1 Location and topographic map of Himalayan orogen. .........................17

Figure 3.2 Major tectonic divisions of Himalaya (Yin 2006). ..............................20

Figure 3.3 Tectonic setup of kumaon-Garhwal himalaya (Valdiya 1980a,b). .........27

Figure 3.4 Litho-stratigraphy of study area (Valdiya 1980a; Virdi 1986). ............34

Figure 4.1 Stability states and destabilising factors (Crozier 1989; Glade and Crozier 2005). .............................................................................................................................................39

Figure 4.2 Geometrical elements for the identification of stress vectors. ............40

Figure 5.1 LISS-IV, Cartosat-1 and Fused image of whole area (Fig.a,b,c); Tangni landslide appears more clearly on merged image than on LISS-4 and Cartosat-1 (Fig. d,e,f); Badrinath and adjacent areas appear much better on merged product compared to LISS-IV and Cartosat-1 Fig.(g,h,i). ....59

Figure 5.2 IRS-P6-LISS IV and Cartosat-1 fused image showing natural, new and anthropogenic landslides and thematic details of the study area. ........64

Figure 5.3 Frequencies of natural and total landslides in different lithological formations. ...............................................................................................................................66
Figure 5.4 (a) Thrust buffer map of study area; (b) Frequency of natural and total landslides in different thrust buffer zones..........................67

Figure 5.5 (a) Lineament buffer map of study area; (b) Frequency of total and natural landslides in different lineament buffer zones.................68

Figure 5.6 (a) Land use/land cover map of the area; (b) Frequency of natural and total landslides in different land use/land cover classes. .................71

Figure 5.7 (a) Geomorphological map of study area, (b) Frequency of natural and total landslides in different geomorphological classes. .................72

Figure 5.8 (a) Slope map of study area; (b) Frequency of total and natural landslides in different slope classes. .............................................73

Figure 5.9 (a) Slope aspect map of the study area; (b) Frequency of natural and total landslides in different slope aspect classes. .....................75

Figure 5.10 (a) Profile curvature map of the study area; (b) Frequency of natural and total landslides in different slope profile curvature classes. ........76

Figure 5.11 (a) Planar curvature map of the study area; (b) Frequency of natural and total landslide in different slope planar curvature classes. ............77

Figure 5.12 (a) Flow length map of the area; (b) Frequency of total and natural landslides in different classes of FL. .................................79

Figure 5.13 (a) FA map of the area; (b) Frequency of total and natural landslides in different classes of FA. ..................................................80

Figure 5.14 (a) SPI map of the area; (b) Frequency of total and natural landslides in different SPI classes. .................................................81

Figure 5.15 (a) TWI map of the area; (b) Frequency of total and landslide landslides in different TWI classes. ............................................83

Figure 5.16 (a) Distance to stream map of the area; (b) Frequency of total and natural landslide in different drainage buffer classes. ...............84
Figure 5.17 (a) Landslide developed by road cutting near Pakhi bridge; (b) bridge damaged by landslide.................................................................85

Figure 5.18 Fluvio glacial deposits are cut six times to build the road (12km before Badrinath). ...........................................................................................................86

Figure 5.19 (a) Road cutting near Paini village; (b) road cutting on steep slopes in progress........................................................................................................87

Figure 5.20 (a) Road cutting related landslides up to 400m in up slope direction; (b) landslide along road NH-58 near Pakhi village.................................88

Figure 5.21 (a) Distance to road map of study area; (b) total and natural landslide frequency in different classes. .................................................................89

Figure 6.1 Venn diagram summarizing the spatial relationship among the causative factor and landslides (Bonham-Carter 2002)........................................91

Figure 6.2 (a) Success rate curve of models, and (b) Prediction rate curve of four best models. .................................................................106

Figure 6.3 Cumulative landslide frequency distribution with respect to total combined weight shows 80 % of landslides in high and very high hazard class with combined total weight value more than -1.1 (on x-axis). ....107

Figure 6.4 Final landslide susceptibility zonation map of upper Alaknanda valley, Garhwal Himalaya, India.................................................................108