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Climate Change accelerating hydrological hazards and risks in Himalaya: A case study through remote sensing and GIS modeling

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ABSTRACT

The main objective of the study was to assess the impact of climate change on hydrological hazards through integrated Database Management System (DMS) on three GIS modules i.e. climate informatics and land use-informatics and hydro-informatics. The Dabka watershed constitutes a part of the Kosi Basin in the Lesser Himalaya, India in district Nainital has been selected for the case illustration. Hydro-informatics module consists of comprehensive study on spring hydrology and stream hydrology to assess several hydrological hazards due to climate change. Land use informatics consists of land use mapping and change diction i.e. decadal changes and annual changes whereas the Climate informatics module consists of spatial distribution of climate and its change detection through daily, monthly and annual weather data (temperature, rainfall, humidity and evaporation) of two study periods i.e. during 1985-1990 and 2005-2010. The spatial distribution of climate throughout study area suggesting three types of climatic zones i.e. sub-tropical, temperate and moist temperate which are respectively favorable for mixed forest, pine forest and oak forest in the mountain eco-system. The results of climate-informatics advocating that all these climatic zones shifting towards higher altitudes due to global climate change and affecting the favorable conditions of the existing land use pattern. In order to that the oak and pine forests have decreased respectively by 25 % (4.48 km^2) and 3% (.28 km^2). The non-forest area has increased dramatically due to lopping and cutting of trees, and growing agricultural activities. The non-forest area has mainly been confined to barren land, riverbed and cultivated land. Barren land increased 1.21 km^2 (56%), riverbed increased 0.78 km^2 (52%) and cultivated land increased about 0.63 km^2 (3%) during the period of 1990 to 2010. The results also advocated that the overall accelerating factor of land use degradation in the study area broadly categorizes as dominant factor and supporting factor. Out of the total seven classes of the land use land cover, five classes (i.e. Oak, Pine, Mixed, Barren and Riverbed) are being degraded dominantly due to climate change factor and anthropogenic factors plays a supporting role whereas only two classes (Scrub land and agricultural land) are being change dominantly by anthropogenic factors and climate change factors plays a supporting role. Expansion of mixed forest land brought out due to upslope shifting of existing forest species due to climate change factor only because upslope areas getting warmer than past with the rate of 9°c-12°c/two decades. Consequently the results concluded that the high rate of land use degradation accelerating several hydrological hazards such as land degradation, high runoff, flash flood, river-line flood, soil erosion and denudation and non-seismic landslides during monsoon season and drought during non-monsoon period as dry-up of natural springs and decreasing trends of stream discharge etc.

Key words: GIS-DMS**,** Climate-informatics, Land use-informatics, Hydro-informatics, Hydrological hazards.

1. Introduction

Dwarfing all other mountains of the world in sheer height, Himalaya is the youngest mountain system, which is still undergoing tectonic movement due to prevailing geological conditions. Though each and every part of the world is more or less susceptible to natural calamities, the Himalaya due to its complex geological structures, dynamic geomorphology, and seasonality in hydro-meteorological conditions experience natural disasters very frequently, especially water-induced hazards (Rawat et. al., 2011). Climate change and land use degradation accelerating these water-induced hazards such as flash flood, river-line flood, erosion, land slide in monsoon period and drought in non-monsoon period (as drying up of natural water springs and streams). The geodynamically active Himalayan terrain is being deforested at the rate of 0.36km^2/year (Rawat and Pant, 2007 and Rawat et al 2010). There are several anthropogenic factors that may contribute to this acceleration, including poorly managed agriculture, forest fire, overgrazing, and substandard construction of roads and buildings. Increasing population and demand of land for agriculture has resulted in pressure in the watershed of the Lesser Himalayan region (Rawat et al. 2011). This is further evident by upslope shifting and destruction of forest land due to climate change. An attempt has been made in the present study to assess the trends of land use pattern in a fragile watershed located near a seismic and tectonically active region. The watershed lies between the latitude 29°24'09"– 29°30'19"E and longitude 79°17'53"-79°25'38"N in the north west of Nainital Township (Fig.1). The region encompasses a geographical area of 69.06 km^2 between 700 m and 2623 m altitude above mean sea level. The total population of the watershed is 9250 people, which includes 16 Villages. The population density is 76.02 person /km$^{2.}$. About 95% population of the total population depends on agriculture and forest resources but the forest cover is decreasing 0.36 km^2 per year. The Geographical Information system (GIS) and Remote Sensing (RS) techniques have recently been widely applied to study land use/land cover changes (Mohanty, 1994; Minakshi *et al*., 1999; Brahmabhatt et al., 2000; and Chauhan et al., 2003). In Himalaya, a variety of changes have emerged in the traditional resource utilization structure mainly in response to population growth and resultant increased demand of natural resources, ineffective technology transfer, market forces, inappropriate land tenure policies, faulty environmental conservation programs, irrational rural developmental schemes, and increasing economic and political marginalization, during the recent years (Palni et al., 1998; Tiwari & Joshi, 1997). These emerging negative trends in the socio-economic profile have resulted into rapid exploitation and transformation of land resources and large-scale land use changes in the region (Tiwari, 1995). Under the impact of various land use systems, the land and whole environment of a geographical region changes positively or negatively. The impact of

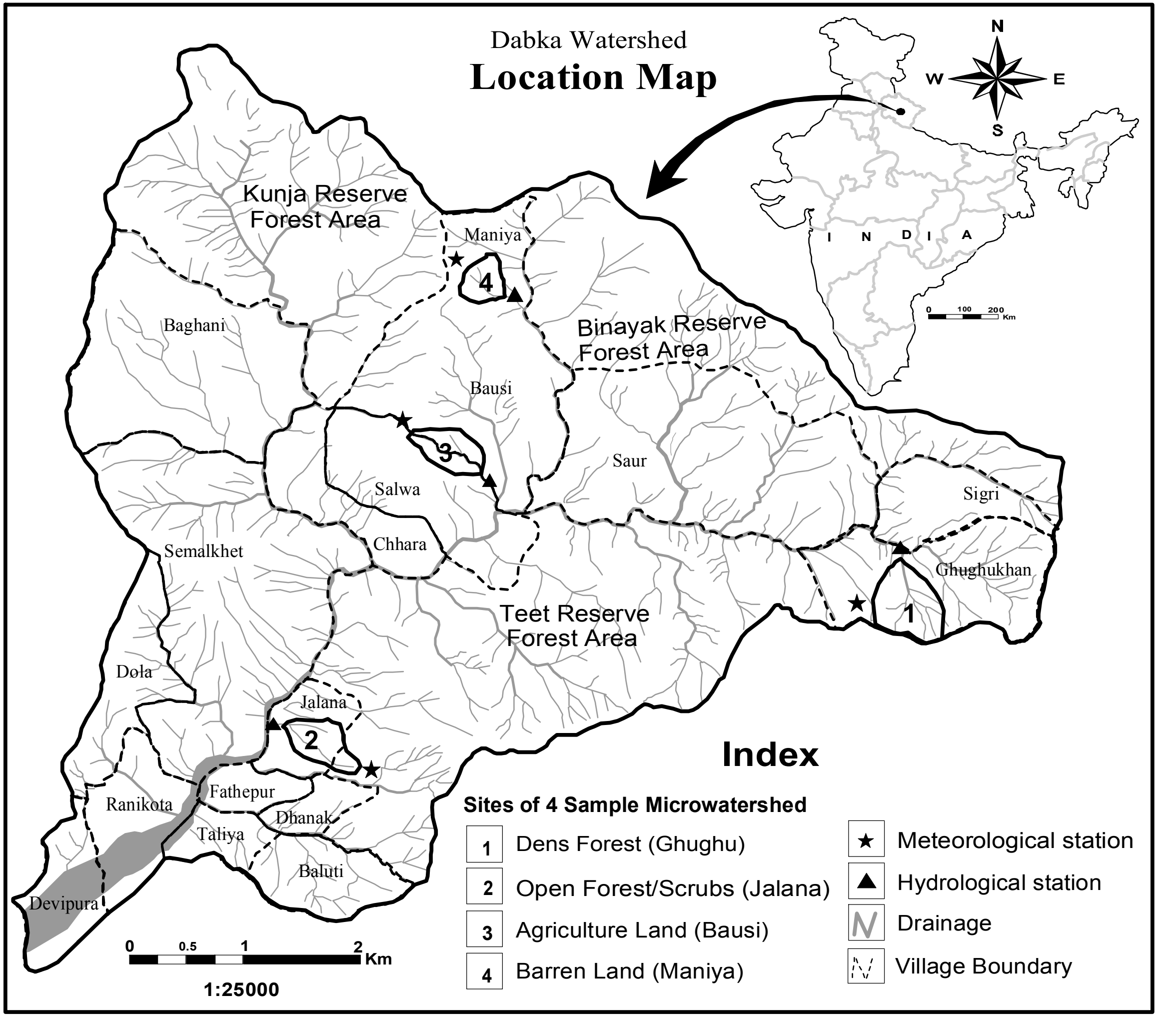

Figure 1: Location Map Showing Selected Sample Micro-watersheds with Sixteen Villages and Location of Hydrological and Meteorological Station Installed in the Study Area

some land use changes is limited to the area in which they are operated while that of others reaches far in the surrounding ecosystems (Kostrowicki, 1983). The extensive land use changes in Himalaya have not only disrupted the fragile ecological balance of the watersheds in the region through deforestation, erosion, landslides, hydrological disruptions, depletion of genetic resources, but have also threatened the livelihood security and community sustainability in mountains as well as in adjoining plainsecosystem (Tiwari, 2000; Tiwari and Joshi, 2002 and 2005). The high rate of land use change accelerating several environmental problems such as high monsoon runoff, flash flood, river-line flood, soil erosion and denudation during monsoon season and drought during non-monsoon period as dry-up of natural springs and decreasing trends of stream discharge etc. These environmental problems cause great loss to life and property and poses serious threat to the process of development with have far-reaching economic and social consequences. Land use degradation due to climate change effecting water resources as drying up of natural water springs and decreasing trends of streams discharge and as a whole triggering other hydrological hazards such as high runoff, flash floods, river-line floods and non-seismic landslide etc. which are mainly responsible for several socio-economic consequences in mountainous terrain (Ives, 1989; Valdiya and Bartarya, 1989; Cruz, 1992; Jain et al, 1994; Sing, 2006; Rawat et. al., 2010). Flash flood in the region cause great loss to life and property and poses serious threat to the process of development with have far-reaching economic and social consequences. About hundreds of peoples are losing their life each year due to flash flood hazard in Himalaya region. On the other hand the river-line flood triggering several environmental socio-economic problems in many ways. River-line flood is undercutting of valley sides which causes the mountainsides to become unstable and ultimately ends in landslides and slope instability which demolished the infrastructural development (road network, buildings, canals, communication connectivity etc) and natural resources specially forest, land and water. During floods, tremendous amounts of erosion occurs on the banks of rivers and streams and washed away the crops and productive land whereas some time moreover, unsorted sediments are deposited over agricultural fields and settlements especially during monsoons.

2. Methodology

The study comprises mainly two components, (a) lab/desk study and (b) field investigations. Geo-structural maps were prepared during field study and details were verified and modified with other maps prepared during the desk study. The procedure adopted for non-seismic landslide hazard mapping has been outlined in Fig. 2 which depicting that study carried out by data integration and superimposition of three GIS module describing as below:

2.1 GIS Database Management System (DMS)

GIS-DMS is a set of computer programs for managing an integrated spatial and attribute database for such a task as map and data input storage, search, retrieval, manipulation and output. Existing DMS is constituted of four different three GIS modules consisting of spatial map layers with their attribute data. These four GIS modules are: climate-informatics, land use-informatics and hydro-informatics respectively for climate change, land degradation and hydrological hazard assessment as describing below lines:

2.1.1 Climate Change Assessment

To assess the climate change during last twenty five years, a comprehensive meteorological study carried out for period 2005-2010 and compared the results of this study with previous study carried out during 1985-1990 (Bight, 1990) from the same study area (i.e. Dabka watershed). Consequentially the spatial distribution of climate throughout study area has been carried out as subtropical climate, temperate climate and moist temperate climate in respect to meteorological data of both study periods. These meteorological data recorded at five meteorological observatories. Four observatories located in sample micro-watershed established at different elevation and running by geology and geography department of Kumaun University and one located at lower elevation of the study area established and running by Irrigation Department of Uttarakhand state government. The four meteorological station running by Kumaun University funded by Govt. of India under different agencies as per their requirement i.e. Department of Environment (1985-1990), Department of Science and Technology (2005-2010) government of India. The meteorological records for a period of twenty five years (1985-2010) depicting that the lowest annual average temperature (18°c) found in year 1990 whereas year 2010 experienced highest annual average temperature (27°c) that's why those years determined as a base years to analysis the climate change and its impact on land use pattern which accelerating several ecological risks through high rate of runoff, rive line flood, flash flood and erosion etc. In order to that the elevation levels of the each meteorological observatory have been determined to delineate isotherms for year 1990 and 2010 and carryout spatial distribution maps of climate for respective year and than superimposed theses spatial distribution maps over the land use map for year 1990 and 2010 to detach the specific impact of climate change on the particular categories of land use land cover.

2.1.2 Land Use Land Cover Mapping and Change Detection

Indian Remote Sensing Satellite (IRS-1C) LISS III and PAN merged data of 1990 and 2010 was used for the analysis and mapping of land cover/ land use for the respective years (Fig. 2). Supplementary data and information required for the study have been generated from various primary as well as secondary sources. The primary information was generated through field surveys, mapping, interviews etc., and the relevant secondary data was collected from various sources, such as, Census of India – 2001, Government, Land Records, forests maps etc. Radiometric corrections were done employing dark pixel subtraction technique. The satellite images of the study area were registered geometrically using SOI Topographical Sheets (56 O/7NE and 56 O/7NW) of the area at scale 1:25000.

For carrying out this important exercise uniformly distributed common Ground Control Points (GCPs) were selected and marked with root mean square (rms) error of one pixel and the images used were resampled by cubic convolution method. Both the data sets were then co-registered for further analysis initially, the LISS and PAN data were co-registered with root mean square (rms) error of 0.3 pixel and the output FCC was transformed into Intensity, Hue and Saturation (IHS) colour space images. The reverse transformation from IHS to RBG was performed substituting the original high-resolution image for the intensity component, along with the hue and saturation components from the original RBG images. This merge data product obtained through the fusion of IRS – 1C LISS – III and PAN was used for the generation of land cover/land use map of the study area for the year 2001, and digital image processing techniques supported by intensive ground truth surveys were used for the interpretation of the remote sensing data (Figure 2).

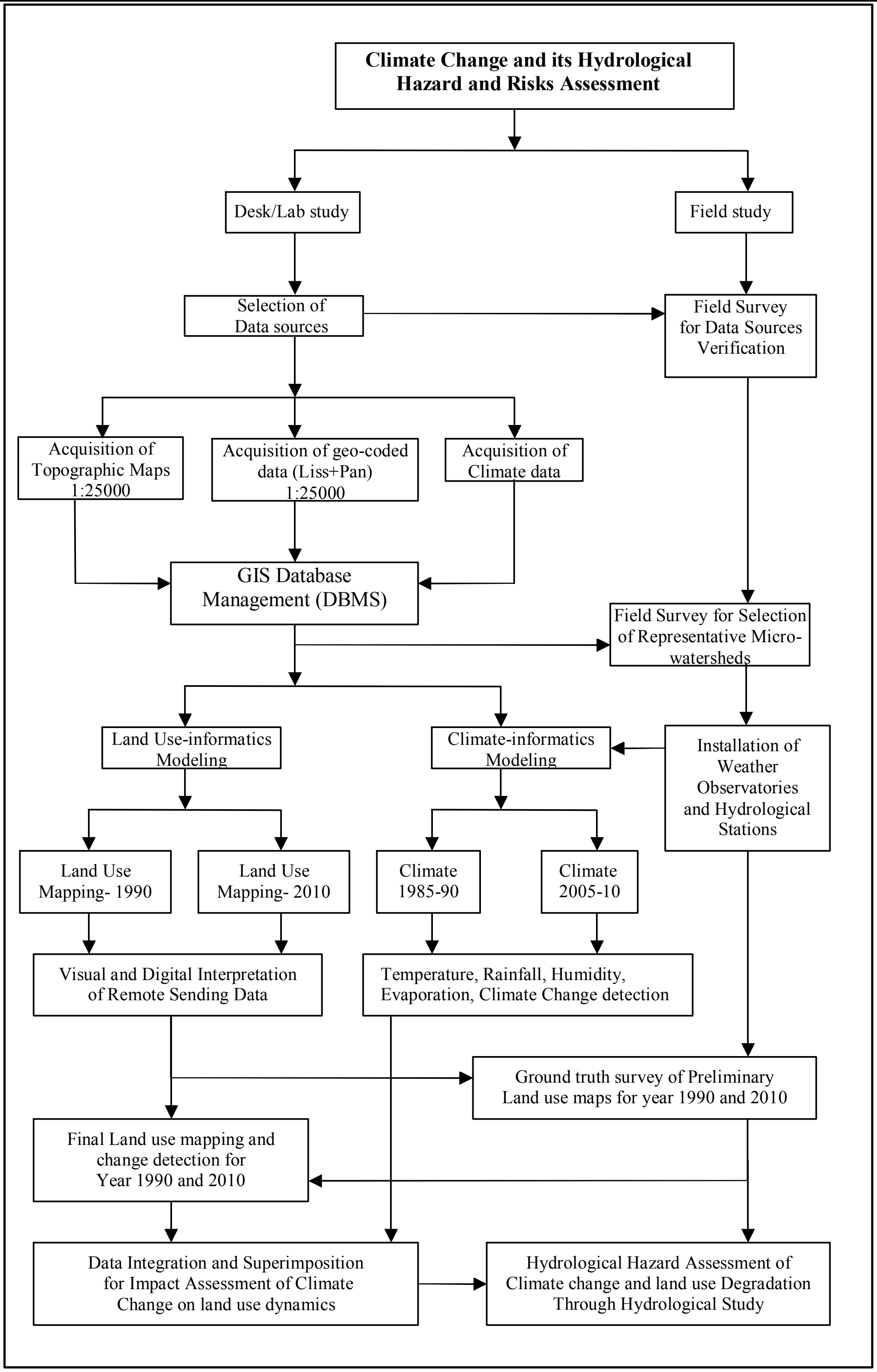

Figure 2: Procedure Adopted for Study

In order to enhance the interpretability of the remote sensing data for digital analysis several image enhancement techniques, such as, PCA, NDVI etc. were employed (Fig. 2). In the Himalayan mountain terrain the interpretability of the remote sensing data to a large extent is affected by the complexity of the terrain as due to the effect of elevation and slope and its aspect, the spectral signature of same objects are often different or vice versa. In order to overcome these constraints and also to attain the best possible level of accuracy in the interpretation, intensive ground truth surveys were carried out in the study region and a visual interpretation key was evolved for primary land cover/land use classification (Table 1).

Table 1: Land Use Interpretation Key

Land Cover/Land Use Classes	Enhanced LISS – III + PAN	
	Tone	Texture
Oak	Red, bright red in south aspects or gentle slopes, dull red and dull tar green in north and steep slopes.	Fine
Pine	Green in the north aspects, red in the south aspects or on the ridges.	Coarse
Mixed Forests	Red interspersing with reddish and dull green	Coarse
Cultivated Land	Reddish and yellowish	Medium/Coarse
Scrub/Barren land	Light cyan interspersing with reddish or yellowish in both the aspects.	Medium
River Beds & Water bodies	Black and Blackish	Coarse

This was followed by the digital classification of land cover/ land use through on screen visual recording and rectification. To monitor the dynamics of land utilization pattern in the study area the land use maps generated for the years 1990 and 2010 were overlaid using Geographic Information System and land use changes were detected and mapped (Fig. 2). The geo-hydrological impacts of land use degradation due to climate change carried out following comprehensive hydrological monitoring (Rawat et. al., 2011).

2.1.3 Hydrological Hazard and Risks Appraisal

To assess the impacts of climate change and land use degradation on hydrological hazards and risks a comprehensive hydrological study on spring hydrology and stream hydrology carried out during 2005-2010 and capered the results with the previous study carried out during 1985-1990 (Bisht, 1990). A number of hydrological hazard and their risks have been carried out and categorised as monsoon hydrological hazard and non-monsoon hydrological hazard following Rawat et al., 2011. Monsoon hydrological hazard comprises of deforestation, high monsoon runoff, flash floods, river-line floods, soil erosion and non-seismic landslide etc. whereas non-monsoon hydrological hazards

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comprises of decreasing under ground water table, drying up of natural water springs and decreasing trends of streams discharge due to deforestation during monsoon period. To identify the environmental and socio-economic impacts of the several monsoonal and non-monsoonal hydrological hazards, a risk map of hydrological hazard has been carried out. The risk level determined as the environmental and socio-economic value of the parameter which is under risks and categorised as low, moderate and high risks following scalogram modeling approach (Cruz, 1992). In order to prepare Risks Index (RI) of the study area, total 6 sets of environmental and socio-economic parameters (X) and their 18 sub-parameters (A) have been taken into account. On the basis of these factors and their sub factors, the following Scalogram model was used for risks zone assessment (After Cruz, 1992).

RI (Score) =[X1 (An) + X2 (An) + X3 (An) + X4 (An) + X5 (An) + X6 (An)]

Where;RI is Risk Index,

X1, X2, X3, X4, X5, X6 are respectively houses and built-up areas, land use pattern, rods, bridle paths and bridges, irrigation cannels and transmission lines, drinking water storage and supply lines and natural water springs (Table 2),.

'An' is total weight score (such as 1+2+3=6) of excising sub-factors or classes (respectively A1, A2 and A3) of a particular major factor (Table 2),

Table 2: Risks Index (RI) includes Six Parameters (X) and 18 Sub-Parameters (A) which have been considered for weight Assignment to Assess the Environmental and Socio-economic Risks Zones of Hydrological Hazards.

Main Parameters (X)	Sub Parameters (A)	Assignment of weightage For Flood Risks index	Risk Potential
Houses and Built-up Areas (X1)	Temporary Shelters	1	Low
	Residential Huts	2	Moderate
	Houses	3	High
Land use Pattern (X2)	Shrubs Land, River beds	1	Low
	Forest Land,	2	Moderate
	Agricultural Land	3	High
Rods, Bridle Paths and Bridges (X3)	Bridle Paths	1	Low
	Roads	2	Moderate
	Bridges	3	High
Irrigation Cannels and Transmission lines (X4)	Gullies	1	Low
	Cannels	2	Moderate
	Transmission Lines	3	High
Drinking Water Storage and supply lines (X5)	Pipe Lines	1	Low
	Tanks	2	Moderate
	Check Dams	3	High
Natural Water Springs (X6)	Dried	1	Low
	Seasonal	2	Moderate
	Perennial	3	High

Each Parameter has three classes or sub-parameters which have been used to assigned weightage for scalogram modeling. These sub-parameters are given in Table 2 which suggests that 1, 2 and 3, respectively denotes low, moderate and higher risk potential according to the economic consequences. Values for the combined weight map ranged from 6-21. In order to prepare a composite risk map of the study area these values (6-21) have been grouped into three classes, i.e. low (below 8), moderate (8-16) and high risk zones (above 16)

3. Results and Discussions

3.1 Climate-informatics

The climate-informatics module consists of comparative study of climatic parameters for a twenty years period during 1990 to 2010 to appraise the impacts of climate change on land use pattern because it's reversely influences the ecology of the watershed and accelerated several environmental and socio-economic risks through high runoff, erosion and sediment delivery during rainy season. Monthly and annual climate data records of two study periods is used to climate spatial distribution mapping for respective year (Table 3 and Fig. 3). A brief account is as follows:

3.1.1 Temperature

The average temperature of the Dabka Watershed is 27ºC in present (2010) and it was about 18ºC twenty years back in 1990 although it varies altitude wise throughout the study area (Table 3 and Fig. 3). June is the driest and hottest month and receives highest annual temperature on the south-facing barren land whereas January is coldest month and receives minimum annual temperature.

Table 3: Seasonal and Annual Climate Change (Carried out by comparative study of two study periods i.e. 1985-1990 and 2005-2010)

Study Periods	**Hydro-meteorological Parameters**	**Seasonal Results**		**Annual Results**
		Non-Monsoon Period	**Monsoon Period**	
Existing (2005-2010)	Temperature (inº C)	16.75	23.75	27.00
	Rainfall (mm)	37.24	393.96	2000.00
	Humidity (in %)	55.19	70.88	52.00
	Evaporation Rate (mm)	603.56	600.17	602.43
Previous (1985-1990)	Temperature (inº C)	10.88	17.00	18.00
	Rainfall (mm)	52.74	424.62	2120.00
	Humidity (in %)	61.38	79.50	60.00
	Evaporation Rate (mm)	543.30	520.10	535.57
Changes (1985-2010)	Temperature (inº C)	5.88	6.75	9.00
	Rainfall (mm)	15.50	30.66	120.00
	Humidity (in %)	6.19	8.63	8.00
	Evaporation Rate (mm)	60.25	80.07	66.86

The annual maximum average temperature found 37ºC in 2010 whereas it was just about 23ºC twenty years back in 1990 (Table 3). The annual minimum average temperature recorded 12ºC in 1990 whereas it is has been rise up to 17ºC in present time by year 2010 (Table 3).

3.1.2 Rainfall

The present average annual rainfall within the watershed varies between 1623 mm and Maniya located in environmentally stressed barren hill slope and 2187 mm at Ghughu located in dense forest hill slope whereas other stations, the annual rainfall amount stand at 1969 mm at Bausi located in agricultural land and 2086 mm at Jalna located in fairly dens forest/shrub land. Throughout the watershed the average annual rainfall is about 2000 mm whereas twenty years back during 1985-1990 it was 2120 mm (Table 3). The results suggested that the annul rainfall pattern has been change and also experiencing that the rainfall season shirking by one to two months (August to September) with the characteristics of extreme rainfall within very small time period which becomes a big threat for hydrological hazards such as erosion, sediment delivery flood landslide and denudation etc. whereas the rainfall records by twenty year back depicting that the rainy season covered completely four months (June to September) having moderate rainfall pattern.

3.1.3 Humidity

The twenty year data analysis suggested that the average annual humidity of the watershed stands at 83.4% which varies between 86% in the dense oak forest area and 64.5% in the south-facing barren land. On other ecological conditions it stands at 80.7% in fairly dens forest/shrub land, 78.5% on the agricultural land agricultural land area. Table 3 suggesting that the average humidity was high than present it has been decreased by 8% annual due to climate change.

3.1.4 Evapotranspiration Loss

The twenty year data analysis suggested that the present annual evapotranspiration loss of the watershed is about 602.43 mm whereas twenty year back it was quit low about 535.57mm. Presently its approaches maximum up to 1072.3 mm on the south-facing barren land and drops down to 559.4 mm on the north-facing oak forest areas of the watershed. On other environmental conditions it was found 786.7 mm, 811.4 mm on the fairly dens forest/shrub land, agricultural land area respectively.

3.1.5 Spatial Distribution of Climate Change

The meteorological records for twenty five years (1985-2010) depicting that the lowest annual average temperature (18°c) found in year 1990 whereas year 2010 experienced highest annual average temperature (27°c) that's why those years determined as a base years to analysis the climate change and its impact on land use pattern which accelerating ecological degradation through deforestation, land degradation, instant rainfall, high monsoon runoff, flash floods, erosion and sediment delivery etc. (Rawat et al. 2011). The climate spatial distribution maps of two study periods (i.e. 1985-1990 and 2005-2010) advocating that all the existing climatic zones (i.e. sub-tropical, temperate and moist temperate) spreading towards higher altitudes due to global climate change and degrading the natural favorable climatic condition of the mixed forest, pine forest and oak forest i.e. respectively sub-tropical, temperate and moist temperate climate (Table 4 and Fig. 3). The results also advocating that the rates of the climate change are high in mountainous areas in compare to plain areas (Table 4 and Fig. 3). It means the rates of climate change are increasing in respect to higher elevation which dominantly effecting the natural vegetation covers throughout the Himalaya up to snow line (6000m). Above the snow line it's also affecting the snow cover which could be the major reason for malting of glaciers in the Himalaya which is a great threat to costal ecosystem due to rising of sea level. In order to monitor the impacts of climate change on land use pattern, the land use interpretation was carried out under land use-informatics module for the years 1990 and 2010 using IRS LISS–III and PAN merged data of respective years.

3.2 Land Use-informatics

As mentioned in methodological section that the land use-informatics module consists of comparative land use land cover mapping for year 1990 and 2010 to assess the changes and identified the accelerating factors for the this changes as discussed in below.

3.2.1 Land Use for year 1990

On the basis of the above exercise, 7 land cover/land use classes could be identified in the study area, for 1990 and 2010 (Fig. 3). Besides the interpretation of the principal land use categories, all the major forest types available in the region could also be identified and mapped during the digital interpretation process. The land use/land cover maps of the study region have been prepared on the scale 1:25000 and classified into 7 categories for both the years (1990 and 2010). The land use classes identified in the watershed include (i) Oak Forests, (ii) Pine Forests, (iii) Mixed Forests, (iv) Scrub Land, (v) Barren Land, (vi) River Beds and Water Bodies, and (vii) Cultivated Land which also includes settlements (Fig. 3). In 1996, out of the total geographical area (69.06 km^2) of Dabka Watershed as much as 39.23 km^2 or 56.81% was under forests.

The forests mainly include Oak Forests, Pine Forests and Mixed Forests, which respectively account for 26.05 % (17.99 km^2), 11.89 % (8.21 km^2), and 18.87 % (13.03 km^2), of total geographical area of the watershed. The scrub land and barren land were respectively extended over 6.38 km^2 (9.24 %) and 2.18 km^2 (3.16 %) of the watershed area. Riverbeds and water bodies occupied only 1.50 km^2 or 2.17 % geographical area of the study region. Nearly 20 km^2 land surface which amounts to nearly 28.63 % of the total area of Dabka Watershed was under cultivation in 1990 (Table 4 and Fig. 3).

3.2.2 Land Use for year 2010

The forest emerged as the major land use/land cover also in the year 2010. A geographical area of 36.77 km^2, which accounts for nearly 53 % of total area of the watershed, has been classified as forests. Due to complexities of terrain and other geomorphic features the forests of the watershed are diversified in nature. Out of the total forest 22.20 % (15.33 km^2) is under mixed forest, 19.56 % (13.51 km^2) is under Oak forest, and 11.48 % (7.93 km^2) is under Pine forests (Table 4). The hilly and mountainous parts of the watershed are covered with Oak and Pine species, whereas, in the lower elevations in the south mixed type of vegetation is very common. Agriculture and settlement are now confined to 20.40 km^2 or 29.54% of the total area. Scrub land, barren land and Riverbeds and water bodies respectively extend over 6.22 km^2 (9.01 %), 3.39 km^2 (4.91 %), 2.28 km^2 (3.30 %) of the total geographical land surface of the study area (Table 4 and Fig. 3).

3.2.3 Land Use Change and Degradation during 1990-2010

In order to monitor the dynamics of land transformation process land use interpretation was carried out for the years 1990 and 2010 using IRS LISS – III and PAN merged data for the respective years. The exercise revealed that oak and pine forests have decreased respectively by 25 % (4.48 km^2) and 3% (.28 km^2) thus bringing a decline of 4.76 km^2 forest in the watershed during 1990 to 2010. But, due to climate change the mixed forest taking place of oak forest in certain pockets and consequently the mixed forest in the catchment increased by 18 % (2.3 km^2) during the same period which reduced the overall loss of forests in the region but its not eco-friendly as the oak forest because the broad leaved and wide spread roots of oak trees helps in controlling the several hydrological hazards such as accelerated runoff, erosion, landslides, flash flood and river-line flood during monsoon period and drought during non-monsoon period. As a result, the watershed recorded a total decline of 2.46 km^2 or 6% forest area during 1990 to 2010 (Table 4 and Figure 3).

The non-forest area has increased dramatically due to lopping and cutting of trees, accelerated runoff, soil erosion and growing agricultural activities. The non-forest area has mainly been confined to barren land, riverbed and cultivated land. Barren land increased 1.21 km^2 (56%), riverbed increased 0.78 km^2 (52%) and cultivated land increased about 0.63 km^2 (3%) during the period of 1990 to 2010 (Table 4 and Fig. 3). The results of land use dynamics presented on Table 4, advocated that the overall accelerating factor of land use dynamics in the study area broadly categoriesed as dominant factor and supporting factor. Out of the total seven classes of the land use land cover, five classes (i.e. Oak, Pine, Mixed, Barren and Riverbed) are being change dominantly due to climate change factor and anthropogenic factors plays a supporting role whereas only two classes (Scrub land and agricultural land) are being change dominantly by anthropogenic factors and climate change factors plays a supporting role. Expansion of mixed forest land brought out due to upslope shifting of existing forest species due to climate change factor only because upslope areas getting warmer than past with the rate of 9○c - 12°c/two decades (Table 4 and Fig. 3).

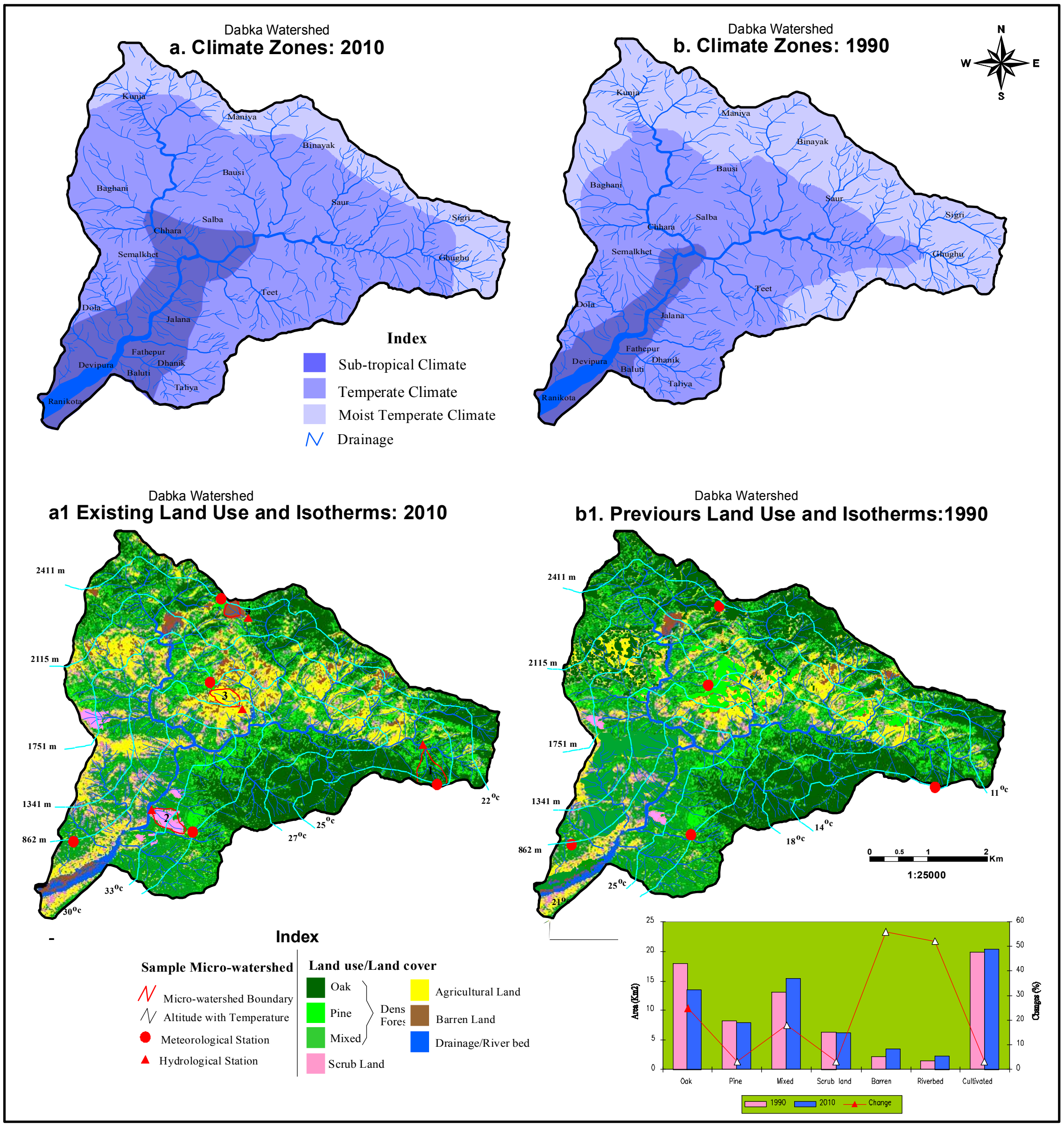

Figure 3: Climate Zones for Year 1990 (a) and its Impact on Existing Land Use Pattern (a1), Climate Zones for Year 2010 and its Impact on Existing Land Use Pattern (b1)

3.3 Hydro-informatics

Hydro-informatics module consists of comprehensive study on spring hydrology and stream hydrology to assess several hydrological hazards due to climate change. These hydrological hazards have been categorized as non-monsoonal hydrological hazards and monsoonal hydrological hazards. A brief discussion on both types of hydrological hazards is given in following sections.

Table 4: Minimum and Maximum Annual Average Temperature Obtained form Five Meteorological Stations in the Watershed for 1990 and 2010 have been used to assess Climate Change (Section A) and its Impact on Land Use Dynamics (Section B)

(A) Climate Change	**Meteorological Observatories with their Location and Established Years**		**Elevation (in m)**	**Minimum Average Temperature (in °c)**		**Maximum Average Temperature (in °c)**		**Annual Average Temperature (in °c)**	
	No.	**Location**		**1990**	**2010**	**1990**	**2010**	**1990**	**2010**
	M^1	Maniya (1985)	2411	6	10	16	33	11	22
	M^2	Ghughu (1985)	2115	8	14	20	35	14	25
	M^3	Bausi (1985)	1751	12	17	23	37	18	27
	M^4	Jalna (1985)	1341	14	20	27	40	21	30
	M^5	Devipura (1978)	862	19	23	30	42	25	33
	Study Area (Average)		**1696**	**12**	**17**	**23**	**37**	**18**	**27**

(B) Land Use Dynamics	**Land Use and Land Cover Classes**	**Year 1990**		**Year 2010**		**Twenty Year Dynamics**	
		km²	**%**	**km²**	**%**	**km²**	**%**
	1. Oak	17.99	26.05	13.51	19.56	-4.48	25
	2. Pine	8.21	11.89	7.93	11.48	-0.28	3
	3. Mixed Forest	13.03	18.87	15.33	22.20	2.3	18
	Total Forest	39.23	56.81	36.77	53.24	-2.46	6
	4. Scrub land	6.38	9.24	6.22	9.01	-0.16	3
	5. Barren Land	2.18	3.16	3.39	4.91	1.21	56
	6. Riverbed	1.50	2.17	2.28	3.30	0.78	52
	7. Cultivated Land	19.77	28.63	20.40	29.54	0.63	3
	Total Non forest	29.83	43.19	32.29	46.76	2.46	8
	Study Area (Total)	**69.06**	**100.00**	**69.06**	**100.00**	-	-

3.3.1 Non-Monsoonal Hydrological Hazards: Accelerated land use degradation due to climate change increasing the deforested land as a result being responsible for drought during non-monsoon periods as decreasing underground water level, drying up perennial springs and streams, decreasing stream discharge. The results of the present study suggested that:

- The land use degradation and deforestation reduced the protective vegetal cover as a result the significant proportion of rainfall goes waste as flood water without replenishing the groundwater reserve. It is experiencing that the ground water level throughout the watershed gradually going down due to deforestation and high flood runoff. The results advocating that twenty year back during 1985-1990 the underground water was easily approachable up to 2000 m altitude whereas now it is quit difficult due to deficiency of under ground water because the water table has been gone down up to just 1200 m altitude (Fig. 4a). The decreasing trends of under ground water table affecting the spring hydrology and stream hydrology in the study area as depicting by a schematic diagram in Fig. 4a for year 1990 and 2010.

- It was observed that, the springs are drying-up or becoming seasonal due to reduced ground water recharge in the catchment. This has serious implications on water resources and on livelihood and food securities as natural springs constitute the main source of drinking water and irrigation in the region. The investigation carried out in the region revealed that there were total 116 perennial springs in the watershed in 1990 (Bisht, 1991), out of which 24% (28) have gone dry, and 28% (32) springs have become seasonal till 2010. In order to that spatial distribution of perennial spring density has been carried out which depicting four categories of density i.e. low, moderate, high and very high. All these categories suggested the decreasing trend of spring density during 1990 to 2010 (Fig. 4b).

- In order to drying up of natural springs the streams depicting decreasing trends of annual stream discharge and becoming perennial to seasonal streams in the study area. The hydrological results suggesting that the existing average annual discharge of Dabka watershed is 13 $l/s/km^2$ whereas during 1985-1990 it was quit high i.e. 17 $l/s/km^2$ (Table 5). It's also found that due to decreasing trends of stream discharge a number of perennial streams have been dried and as a result decreasing the perennial stream frequency throughout the sturdy area. In order to that Fig. 4c depicting four categories (low, moderate, high and very high) of the spatial distribution of perennial streams frequency and advocating that perennial stream frequency has been decreased during 1990 to 2010 due to climate change through drying up of natural water springs and decreasing trends of stream discharge.

3.3.2 Monsoonal Hydrological Hazards: Increasing rates of land use degradation and extensive rainfall within short time period due to climate change accelerating several monsoonal hydrological hazards and their risks in Himalalaya. Accelerated land use degradation due to climate change increasing the deforested land as shrubs land, barren land, river bed etc. The land use study revealed that oak and pine forests have decreased respectively by 25 % (4.48 km^2) and 3% (.28 km^2) thus bringing a decline of 4.76 km^2 forest in the watershed during 1990 to 2010 which is a key factor for several hydrological hazards during monsoon period i.e. high monsoon runoff, flash floods, river-line floods, soil erosion and non-seismic landslide etc. In order to that the comparative hydrological evaluation of two study periods is resulted that:

- The monsoon flood runoff (June to September) is increasing because of accelerated land use degradation due to climate change. These data advocate that the dense forested land due to broad leaved spices of trees has very high and the deforested barren land has very low water retention capacity within their hydrological system. Although all monsoon months have high runoff but particularly August month receives maximum monsoon runoff due to extreme rainfall (Table 5). Consequently the average monsoon flood runoff of August month during 2005-2010 found 1235 l/s/km^2 whereas in the same month during1985-1990 it was quit low with the rate of 1076 l/s/km^2 (Table 5). The spatial distribution of flood runoff for year 1990 and 2010 has been demonstrated by Fig. 5a.

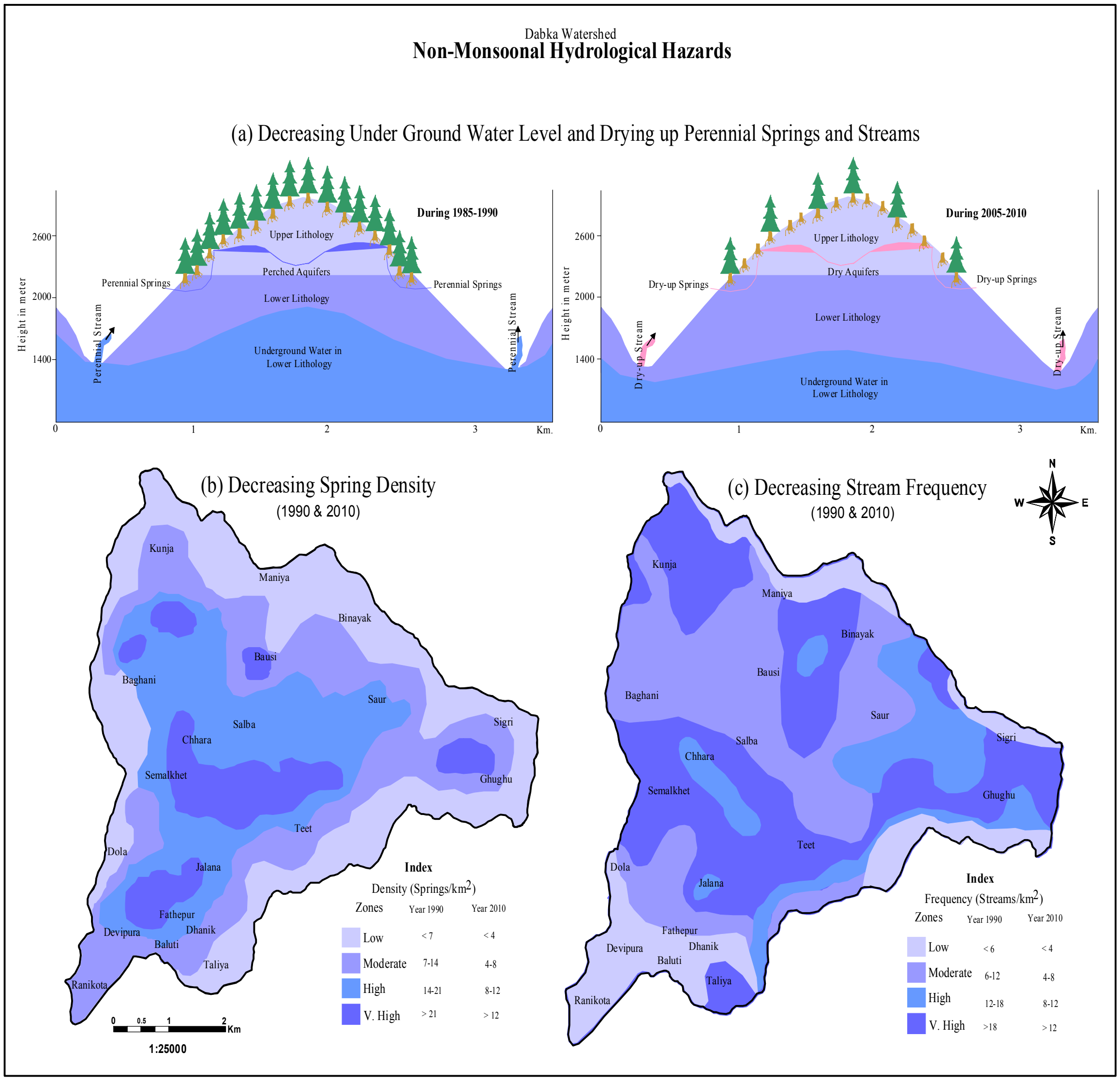

Figure 4: Non-Monsoonal Hydrological Hazards due to Climate Change and Land Use Degradation During 1990-2010 in Himalaya i.e. Decreasing

Ground Water Level, Drying up Perennial Springs and Streams (a), Decreasing Spring Density (b) and Decreasing Stream Frequency (c).

Table 5: Changes in Hydro-meteorological Parameters of the Dabaka Watershed due to Climate Change and Land use Degradation

Study Periods	Hydro-meteorological Parameters	Seasonal Results		Annual Results	Denudation rate in mm/year
		Non-Monsoon Period	Monsoon Period		
Existing (2005-2010)	Temperature (in° C)	16.75	23.75	27.00	0.68
	Rainfall (mm)	37.24	393.96	2000	
	Stream Discharge (l/s/km^2)	6.65	37.19	16.82	
	Flood Runoff (l/s/km^2)	169.76	966.40	435.31	
	Bed Load (t/km^2)	2.47	25.86	124.50	
	Suspended Load (t/km^2)	1.08	12.45	58.50	
	Dissolved Load (t/km^2)	0.51	7.61	34.50	
	Total Load (t/km^2)	4.15	47.25	224.45	
Previous (1985-1990)	Temperature	10.88	17.00	18.00	0.42
	Rainfall	52.74	424.62	2120	
	Stream Discharge (l/s/km^2)	4.03	31.44	13.17	
	Flood Runoff (l/s/km^2)	144.13	842.77	377.01	
	Bed Load (t/km^2)	1.90	17.43	84.92	
	Suspended Load (t/km^2)	0.79	10.22	47.19	
	Dissolved Load (t/km^2)	0.38	5.95	26.82	
	Total Load (t/km^2)	3.06	33.61	158.93	
Changes (1985-2010)	Temperature	5.88	6.75	9.00	0.26
	Rainfall	13.25	18.16	48.49	
	Stream Discharge (l/s/km^2)	2.62	5.74	3.65	
	Flood Runoff (l/s/km^2)	25.64	123.63	58.30	
	Bed Load (t/km^2)	0.57	8.43	39.58	
	Suspended Load (t/km^2)	0.29	2.23	11.31	
	Dissolved Load (t/km^2)	0.13	1.66	7.68	
	Total Load (t/km^2)	1.09	13.64	65.52	

- Under natural circumstances the total sediment load of streams varied from 66 tons/km^2/year in the dense forest to 398 tons/km^2/year in the barren land in the watershed (Table 4). Anthropogenic activities have accelerated the rate of load generation by 4 times (302 tons/km^2/year) in agricultural land and 6 times (398 tons/km^2/year) in barren land. Presently the average rate of total load delivery from Dabka watershed stands at 224.45 tons/km^2/year whereas twenty years back during 1985-1990 it was just 158.93 tons/km^2/year (Table 5). In order to that the average annual rate of soil erosion of the Dabka watershed stands on 0.68 mm/year in present time it was just 0.42 mm/year twenty years back during 1985-1990 (Table 5). The spatial distribution map of soil erosion and denudation depicting five zones and advocating that the soil erosion and denudation rates has been increased (Fig. 5b and Table 5) due to climate change and land degradation.

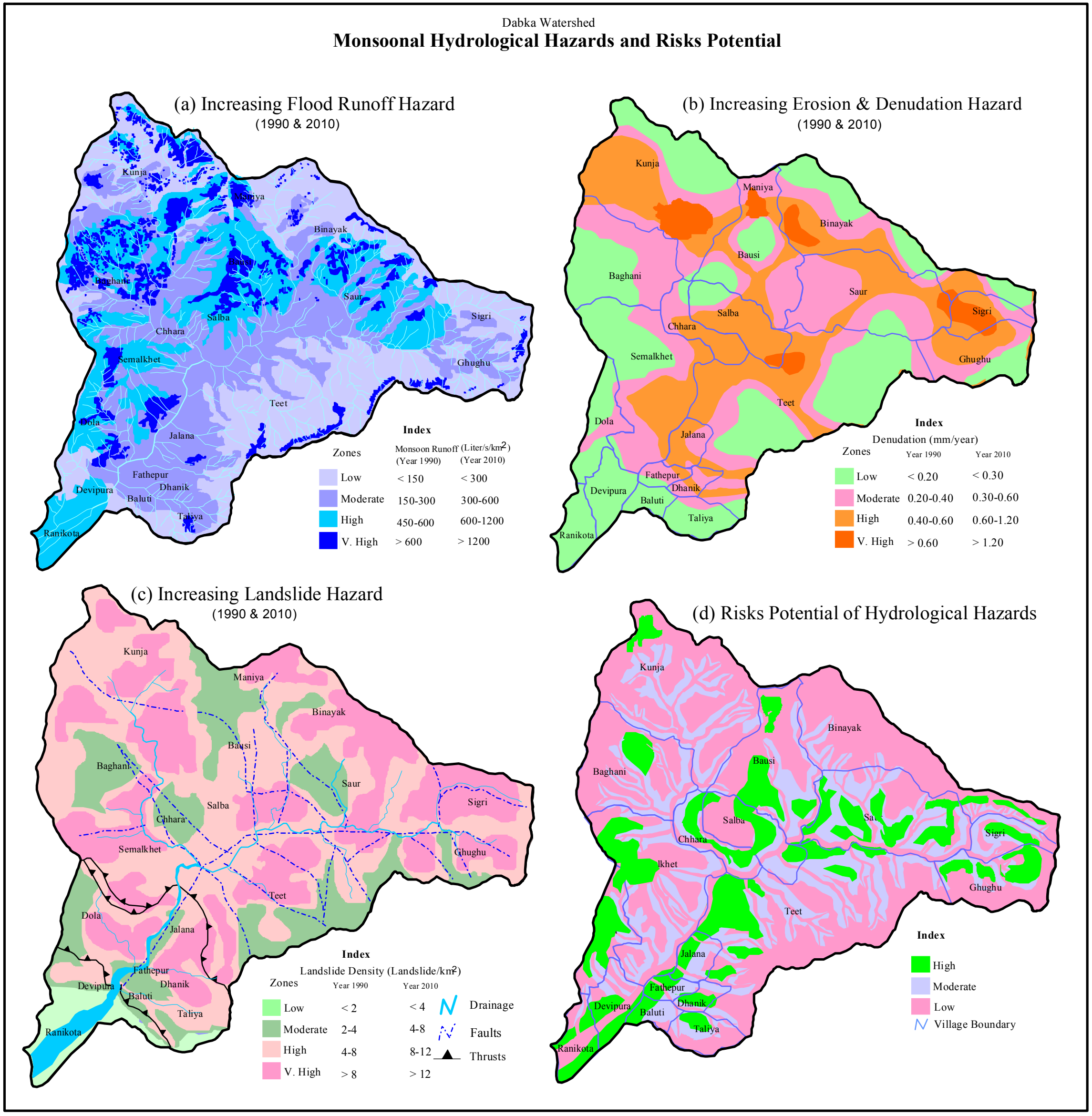

Figure 5: Monsoonal Hydrological Hazards due to Climate Change and Land Use Degradation During 1990-2010 in Himalaya i.e. Increasing Flood Runoff Hazard (a), Increasing Erosion and Denudation Hazard (b), Increasing Landslide Hazard (c), Integrated Risks Potential of these Hydrological Hazards (d).

- After delineating all the exiting landslides during field work a spatial distribution and density map of landslides have been carried out by GIS mapping following grid and isopleth's technique (Fig. 5c). The map suggesting that the maximum area of the watershed has very high to high spatial density of landslide which stands respectively 39% (26.93 km^2) and 32% (22.10 km^2) area of the watershed whereas minimum area of the watershed about 7% (4.83 km^2) occupied by low spatial density of landslide. Moderate spatial distribution density of landslide covers about 22% (km^2) area of the watershed (Fig. 5c). Low and moderate spatial landslide density zone have respectively less than 4 and 4-8 landslide/km^2 whereas high to very high landslide spatial density zone have respectively 8-12 and above 12 landslide/km^2 (Fig. 5c).

- Fig. 5d suggesting integrated risks potential of non-monsoonal and monsoonal hydrological hazards due to climate change and land use degradation as described in below section.

3.4 Risk Appraisal of Hydrological Hazards

To appraise the environmental and socio-economic consequences of hydrological hazards due to climate change and land use degradation in the study area, a risks zone map has been prepared and the description is given below:

3.3.1 Area under Low Risks Zone

This category of risks has been mainly identified in the areas of high altitudinal zones such as ridges and structural hills. These areas mainly fall under forest, wasteland, channel beds and scrubland of the watershed (Fig. 5d). Out of the total area of the Dabka Watershed 51.37 km^2 or 74% is under low risk potential zone of hydrological hazards (Fig. 5d).

3.3.2 Area under Moderate Risks Zone

Pediment areas of the watershed have been identified as the areas showing moderate potential to the risks. The moderate risk potential areas are located along streams, on alluvial and fluvial fans (Fig. 5d). Out of the total area of the Dabka Watershed 7.06 km^2 or 10% is under moderate risk potential zone of hydrological hazards (Fig. 5d).

3.3.3 Area under High Risks Zone

Human settlements, water-mills, roads, canals and cultivated land, river terraces etc. of the watershed have been identified as the areas subjected to high risk potential (Fig. 5). Out of the total area of the Dabka Watershed 10.63 km^2 or 15% is under high risk potential zone hydrological hazards (Fig. 5d).

4. Conclusion

The GIS modeling on climate-informatics and land use-informatics advocated that the overall accelerating factor of land use degradation in the study area broadly categories as dominant factor and supporting factor. Out of the total seven classes of the land use land cover, five classes (i.e. Oak, Pine, Mixed, Barren and Riverbed) are being change dominantly due to climate change factor and anthropogenic factors plays a supporting role whereas only two classes (Scrub land and agricultural land) are being change dominantly by anthropogenic factors and climate change factors plays a supporting role. Expansion of mixed forest land brought out due to upslope shifting of existing forest species due to climate change factor only because upslope areas getting warmer than past with the rate of 9°c-12°c/two decades. Consequently the results concluded that the high rate of land use change accelerating several hydrological hazards such as deforestation, land degradation, high runoff, flash flood, river-line flood, soil erosion and denudation during monsoon season and drought during non-monsoon period as dry-up of natural springs and decreasing trends of stream discharge etc. These hydrological hazards cause great loss to life and property and poses serious threat to the process of development with have far-reaching economic and social consequences.

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