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Uttarakhand Science Education and Research Centre (USERC)

Department of Science and Technology (Govt. of Uttarakhand), Uttarakhand

Uttarakhand

State of the Environment Report-2012

U t t a r a k h a n d S O E R - 2 0 1 2



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Section III



CLIMATE CHANGE

Climate Change

Chapter

ONE

CLIMATE CHANGE

(JS Rawat, Rajendra Dobhal
and VPS Arora)

1.1. Introduction

Uttarakhand having a complex geographic personality is miniature of the earth as it has almost all the climatic and vegetation regions of the world. Uttarakhand mountain system delivers a wide array of goods and services to humanity such as fresh water, carbon storages, biodiversity, forest products, agricultural and horticultural products, minerals, electricity, recreation opportunities and many others. All these services are exposed to climate change on multiple fronts. The functioning of fragile mountain system is threatened today by global warming accelerated alarmingly by various anthropogenic and technogenic activities. It is not an easy task to define the impact of climate change on different resource sectors without understanding anthropogenic and technogenic impacts in different systems. It is a challenging task for the scientists and Uttarakhand is an excellent state to assess the various impacts of climate change because it has still some virgin or anthropogenically least affected alpine and snow cover area in its high altitudinal zone, and has a good amount of anthropogenically least affected forest area.

This paper provides preliminary results of climate change impact studies on temperature and rainfall, snow cover and glaciers, biodiversity, streams and rivers, agriculture and other sectors conducted by UCCC in Uttarakhand and also embraces an overview of long term action plan initiated by UCCC for climate change impacts mitigation in association with villagers, government departments and scientists.

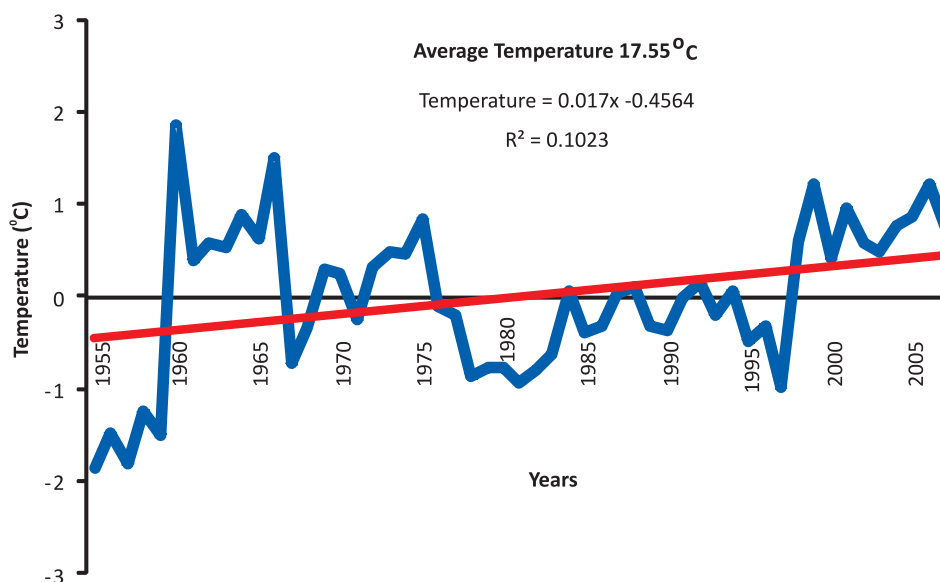
1.2. Temperature and Rainfall

1.2.1. Increase in Temperature

Global warming is a universal phenomenon but how much a particular region or place has warmed actually, it has to be determined region to region and place to place. The observations of available temperature data reveal that since the last 53 years (1955 to 2007) average temperature of a Lesser Himalayan Hill station, viz., Almora -located at 29°35' and 79°35'E at an elevation of 1640m from the m.s.l. has an increasing trend (Fig. 1.1) due to anthropogenically accelerated global warming. These data indicate that the average temperature of Almora, i.e., 17.55°C (1955-2007) has increased up to 0.46°C during the last 53 years. This preliminary observation suggests that the average temperature is rising in hills. The amount of temperature rise may vary from place to place which has to be

Fig-1.1.

Variation in average annual temperature and its trend at Almora².





determined by further studies. Similar temperature study in Changbaishan Natural Reserve in the neighboring country China has also reported the increasing trend in the average annual temperature from 1982 to 2002¹.

1.2.2. Reduction in Annual Rainfall

Rainfall records of two places, i.e., Almora and Manora Peak (Nainital) were examined. These results have indicated that annual rainfall has decreasing trend. The rainfall record of 53 years (1955 to 2007) of a Hill Station of Uttarakhand, viz., the Almora, postulates the fact that the average annual rainfall has a decreasing trend (Fig. 1.2). At present, on an average, the Almora Hill Station is receiving 23% or 244 mm less annual rain compared to its 53 years annual average rainfall, i.e., 1060 mm. The rainfall records of 40 years (1964-2003) of the Manora Peak near the Nainital town also reveal that the annual rainfall has decreasing trend (Fig.1.3). The average rainfall (1964-2003) of the Manora is 2324 mm. At present this area is receiving about 16% (or 332 mm) less rainfall from its annual rain (i.e., 2324 mm).

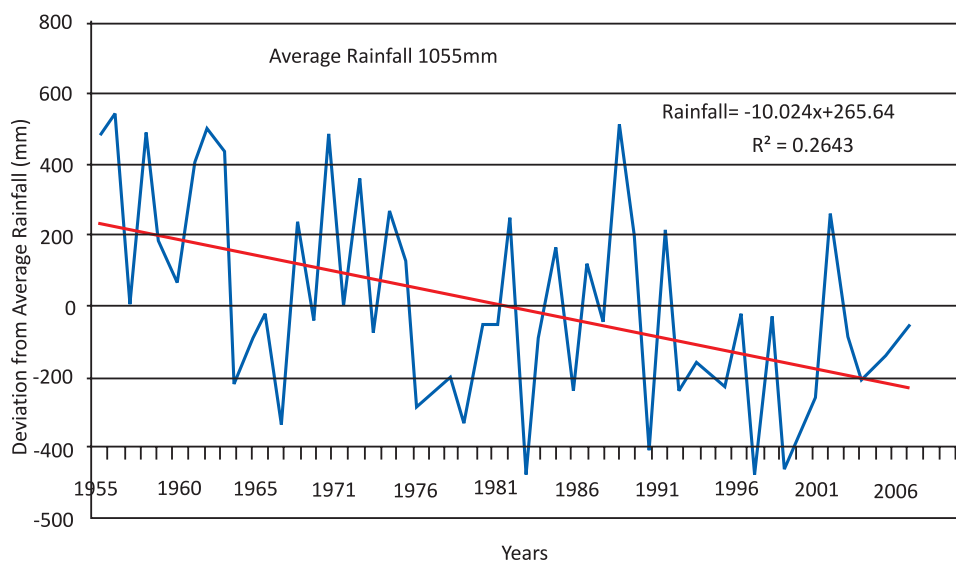
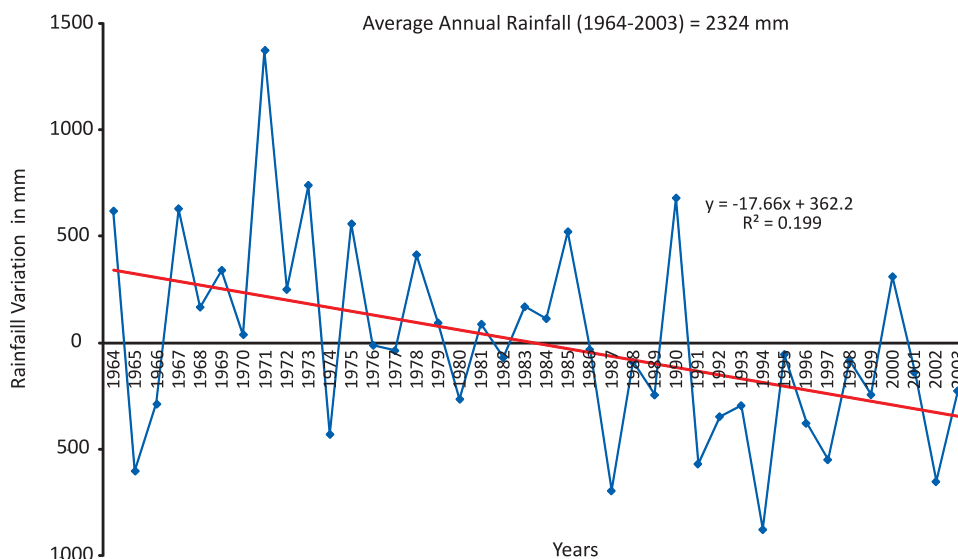


Fig-1.2.

Variation from average rainfall and its trend at Almora².

Fig-1.3.

Variation from average rainfall and its trend at Manora Peak².

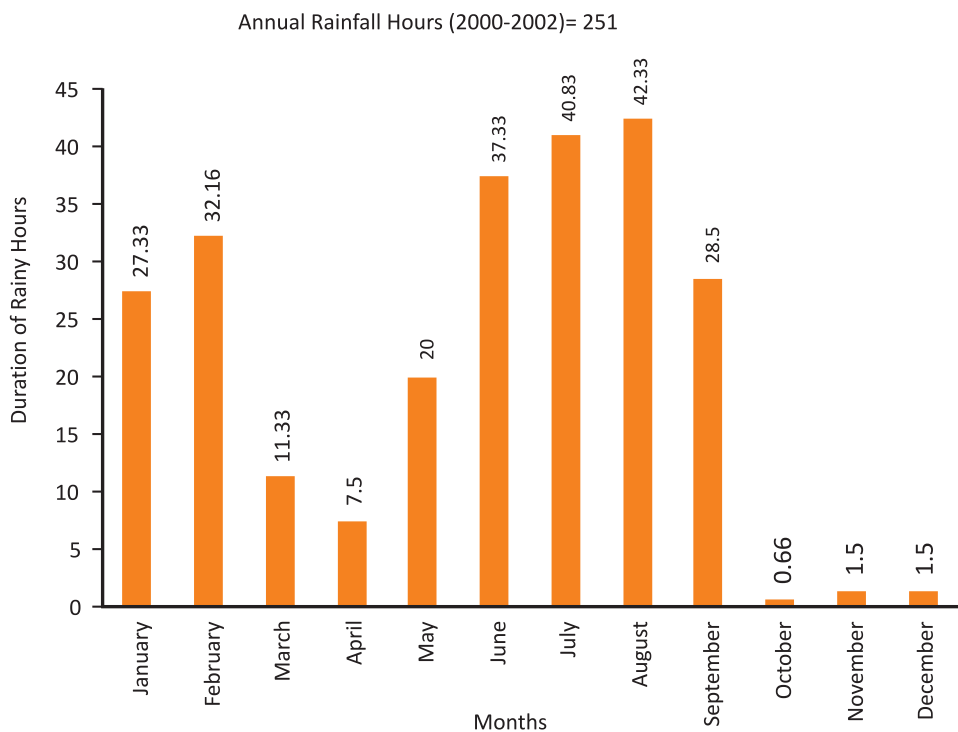


1.2.3. Reduction in Annual Rainy Hours

The latest available rainfall duration records on hour by basis of village Sall Rautela (Fig. 1.4) in district Almora reveal that average annual rainfall duration stands at about 251 hours/year which varies between 0.66 hours in October to 42.33 hours in August. Although such hourly basis records of rainfall are not available of the past for comparison but most of the natives of the state having age of more than about 50 to 60 years would have not forgotten the popular geographic phenomenon which used to occur in the recent past normally in mid July, viz., *Satzhar*, i.e., rain of continuous seven days. This rainfall duration of seven days (i.e., 168 hours) is more than the present entire rainy season (June to September) rainfall duration, i.e., 147.99 hours (Fig. 1.4).

Fig-1.4.

Average monthly rainfall hours (2002-2003) at Village Salla Rautela, District Almora².





State Climate Change Council

As concluded in the 'Shimla Conclave' held in Oct 2009, Uttarakhand state has crafted its own State Climate Change Council under the chairmanship of the Chief Secretary, Government of Uttarakhand and additional PCCF as a member Secretary (Order No. 37/X-3-2010-13(12)/2009 dated 19 Jan 2011)

The council has members belonging to 27 different departments. The departments are Forest, Climate Change and Forest Influence Division, Forest Research Institute, Rajaji National Park, H N B Garhwal University, Agriculture Department, Industries, Urban Development, Watershed Management Directorate, Animal Husbandry, Power Transmission Corporation of Uttaranchal Ltd (PTCUL), Planning Department, Uttarakhand State Council for Science and Technology, SIDCUL, Uttarakhand Jal Sansthan, Disaster Mitigation and Management Centre (DMMC), Uttarakhand Peyjal Sansadhan Evam Nirman Nigam, State Water and Sanitation Mission, Uttarakhand Renewable Energy Development Agency (URED), Uttarakhand Power Corporation Limited, Transport, Directorate General of Health Services, NRHM, Biodiversity Board, Tourism, Uttarakhand Jal Vidyut Nigam, SWAJAL and PWD.

The mandate of the council is to approve, implement and monitor the state level work plan for climate change. It will also update the state about the various programmes initiated globally as well as in the domestic level and contextually implement the ones relevant for the state.



These data suggests that the actual rainfall duration has been reduced to 75% less in the month of July alone. The situation is similar in case of the other months also but no hourly basis rainfall records of past are available to compare. The automatic rain gauge record of the Salla Rautela village is symbolic which advocates that the actual annual rainfall duration has been drastically reduced due to climate change.

1.2.4. Changes in Rainfall Rhythm

The normal monthly distribution of rainfall in the region reveals that the maximum rainfall occurs in the month of July which constitutes the peak of the annual hyetograph and the months August and September constitute the recession segment of the hyetograph. The recent rainfall records (2000-2002) suggest that the peak of annual hyetograph has been shifted from July to August (Fig. 1.5) and since the last two decades there are incidences when the peak of the annual hyetograph is being formed in the month of September (Fig. 1.6). This indicates that in future the peak of the annual hyetograph may be shifted from August to September. The shifting of rainfall peak in the annual hyetograph reveals that the rainfall rhythm is gradually changing due to climate change.

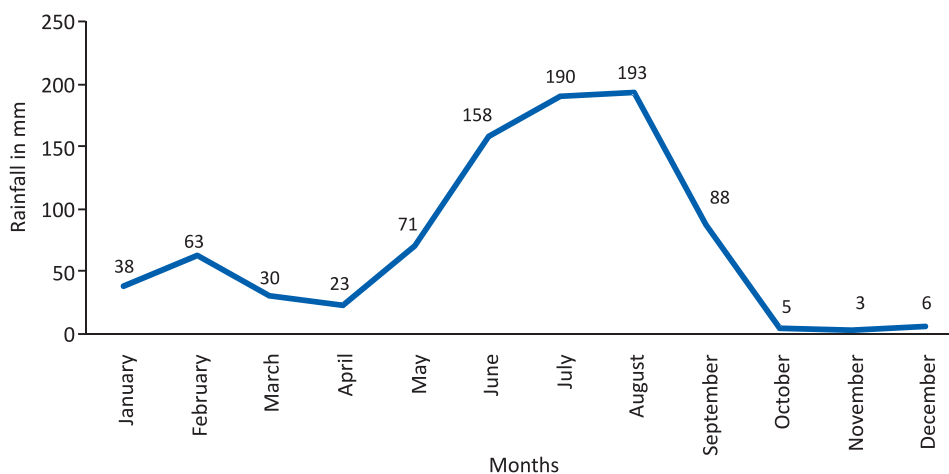
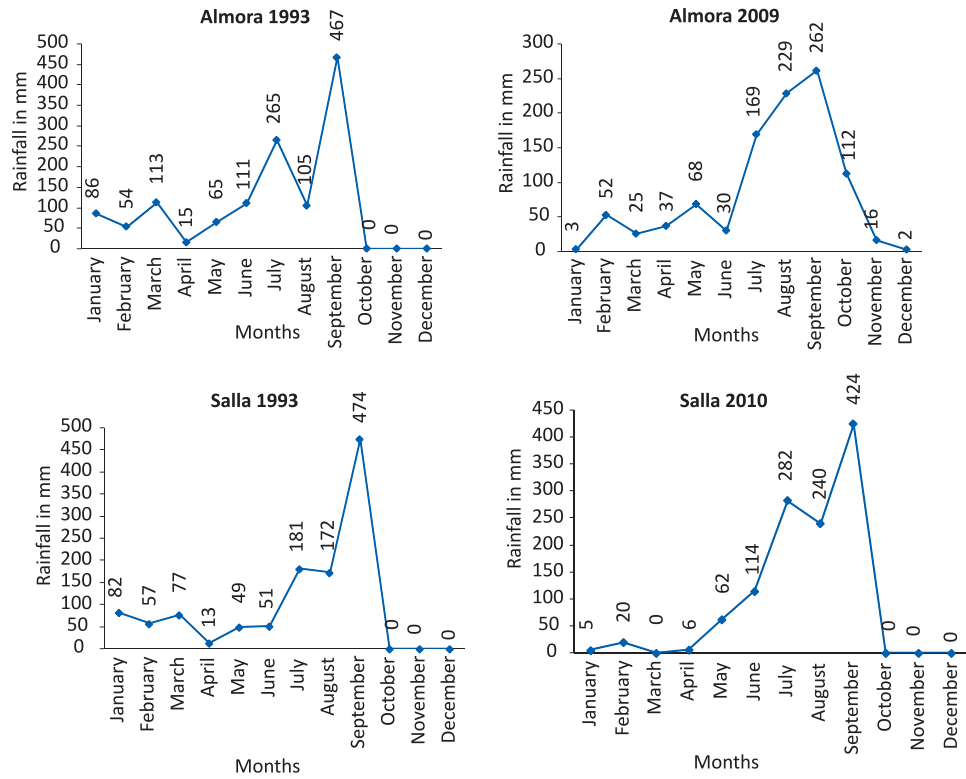


Fig-1.5. Average annual hyetograph (2002-2003) of Village Salla Rautela showing the peak of hyetograph in month of August².

Fig-1.6.

Annual hyetographs of the Almora town (data after VPKAS Almora) and village Salla Rautela² showing the peak of hyetographs in the month of September.

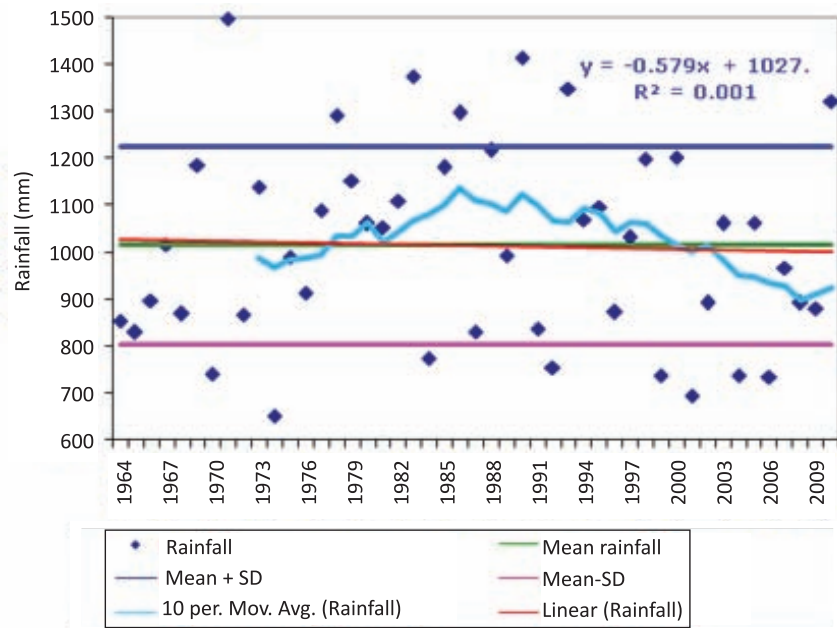


1.2.5. Increasing Trend of Draught Years

Due to climate change there has been increasing trend of occurrence of draught incidences in the recent past. The Hawalbagh rainfall record postulates this fact revealing that during 1964 to 2000 the total incidences of draught were 16, out of which 5 were severe but during 2001-2009 within 8 years, 7 draughts occurred out of which 3 were severe (Fig. 1.7).

Fig-1.7.

Rainfall pattern at Hawalbagh, district Almora (After Pandey, VPKAS Almora).



1.3. Snow and Glaciers

1.3.1. Snow Cover

Snow cover is highly sensitive for climate change impact. Geographical distribution of snow cover area on different dates in different watersheds (Table 1.1) and in the entire state of Uttarakhand was worked out from the available remote sensing data. Fig. 1.8 depicts example of distribution of snow cover area in different years in one of the watersheds of Uttarakhand, viz, the Kuthiyangti while Fig. 1.9 depicts status of change in snow cover area in Uttarakhand from 1990 to 1999, i.e., a period of about one decade.

Name of Watershed	Area of Watershed in km ²	Area under Snow Cover Area	
		Year	In %
1. Kuthiyangtai	639.89	October, 1972	69.8
		15 th October, 1990	64.4
		15 th October, 1999	56.7
		15 th October, 2010	44.5
2. Dhauliganga (E)	1432.36	October, 1972	62.4
		15 th October, 1990	40.0
3. Goriganga	2279.71	15 th October, 1990	27.6
		15 th October, 1999	25.9
4. Ramganga (E)	1282.32	October, 1972	1.7
		15 th October, 1990	1.3
5. Pindar Watershed	1872.98	October, 1972	12.5
		15 th October, 1999	8.6
6. Dhaul Ganga (W)	3210.67	15 th October, 1990	63
		15 th October, 1999	42
7. Dhaul Ganga (E)	1432.36	October, 1972	62.4
		15 th October, 1990	40.0
8. Alaknanda	3414.64	October, 1972	38.0
		15 th October, 1999	34.1
9. Bhagirathi	6073.25	October, 1972	45.8
		15 th October, 1999	22.6
10. Mandakini	1667.75	October, 1972	14.2
		15 th October, 1990	12.8
11. Yamuna	5165.21	October, 1972	16.9
		15 th October, 2010	10.6

Table-1.1.

Geographical area under snow cover on different dates in different watersheds and in the Uttarakhand state (based on MSS and LANDSAT TM and ETM Data)

Table 1.1 reveals that the snow covered area in different watersheds of Uttarakhand varies maximum 56.7 to 69.8% in Kuthiyangti watershed to minimum 1.3 to 1.7% in the Eastern Ramganga watershed. The geographical distribution of snow reveals that on 15th and 21st October 1990, about 4884.29 km² area of the Uttarakhand state was under snow cover while on the same dates and month in 1999, the snow cover was found in 4145.95 km² area. This reveals that the snow cover area was about 17.98% (or 738.34 km² - Fig. 1.9) less in Uttarakhand in October 1999 as compared to October 1990, i.e., within a period of about one decade.

Fig-1.8. Geographical distribution of snow cover area and NDVI based vegetation line in different years in the Kuthiyangti Watershed² (based on MSS, LANDSAT TM and ETM+ data of October 1972, 15th October 1990, 15th October 1999 and 15th October 2010).

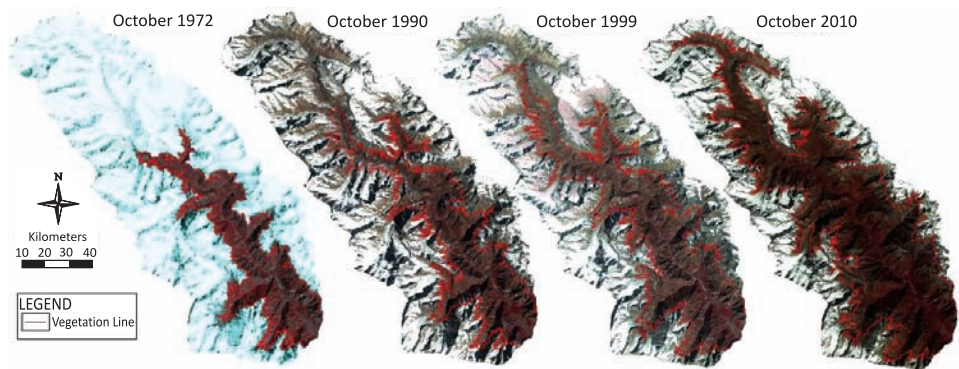
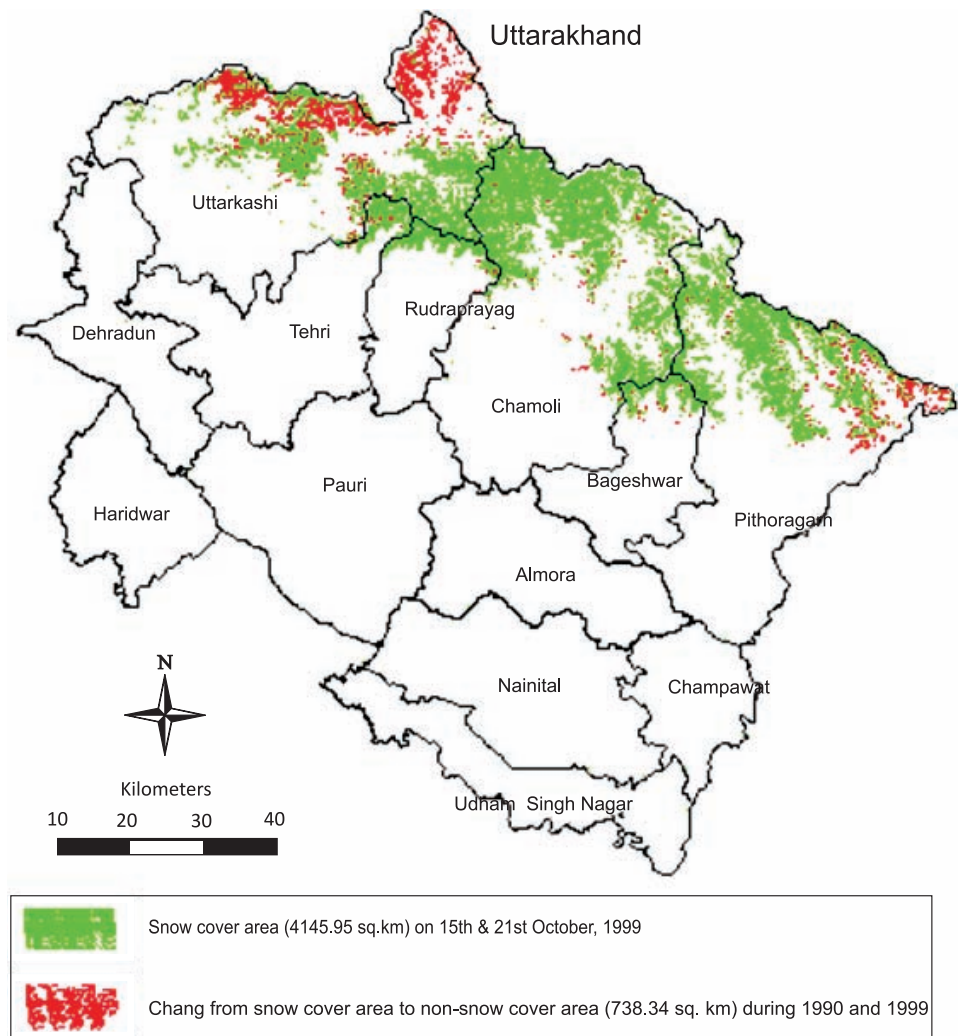


Fig-1.9.

Difference in snow cover area between October 1990 and October 1999 in the Uttarakhand State² (based on 15th and 21st October 1990 LANDSAT TM data and 15th and 21st October 1999 LANDSAT ETM+ data.)



1.3.2. Glaciers

Snow is very sensitive for global warming. Results of studies from Uttarakhand (Table-1.2) reveal that the glaciers of Uttarakhand are retreating at different rates in different time periods depending on their different geographic position, aspect and altitude. The Pindari glacier has retreated about 2840 m since the last 121 years at an average rate of 23.47 m/

year. It retreated at the rate of 26.22 m/year during 1845 to 1906, 20 m/year during 1906 to 1958 and 25 m/year during 1958 to 1966 (Table-1.2). The Raktvarna and Thelu glaciers (Plate-1.1 and 1.2) have retreated 1248 m (at the rate of 30.66 m/year) and 1585 m (at the rate of 37.73 m/year) during the last 42 years between 1962 to 2004. A glacier is a system of many smaller glaciers. For example the Gangotri glacier is system of as many as 32 tributary glaciers ranging from 1.05 km² to 17.70 km² in area⁴. The tiny and small glaciers are retreating relatively at faster rate. For example, Chhanguch, a tributary glacier of the Pindari, retreated at more than 10 times higher rate (i.e., 85 m/year) during 1958 to 1966 as compared to the retreat rate (i.e., 25 m/year) of its master Pindari glacier (Table-1.2). Similarly the rate of retreat of the two tributary glaciers, viz., the Raktvarna (Plate-1.1) and Thelu (Plate-1.2) is near about two times higher as compared to the retreat rate (19 m/year) of their master glacier, viz., the Gangotri (Plate-1.3). Numbers of tiny and small glaciers have completely disappeared from the region which is not documented.

S. No.	Name of Glacier	Period	Duration	Recession	Rate of Retreat
1	Gangotri	1936-1996 ³	61 years	1147m	19m/year
2	Pindari	1845-1906 ^{4,5}	61 years	1600m	26.22m/year
		1906-1958 ⁶	52 years	1040m	20.0m/year
		1958-1966 ⁷	8 years	200m	25.0m/year
		1885-1966 ⁸	121years	2840m	23.47m/year
3	Milam	1849-1957 ⁹	108 years	1350m	12.5m/year
4.	Dokriani	1962-1991 ⁹	29 years	480m	16.5m/year
		1991-2000 ⁹	9 years	161.15m	18.0m/year
Tributary Glaciers					
1	Chhanguch	1958-1966 ⁸	8 years	680m	85m/year
2	Thelu	1962-2004 ¹⁰	42 years	1248m	30.66m/year
3	Raktvarna	1962-2004 ¹⁰	42 years	1585m	37.73m/year

Table-1.2.
Rate of recession of different glaciers of Uttarakhand

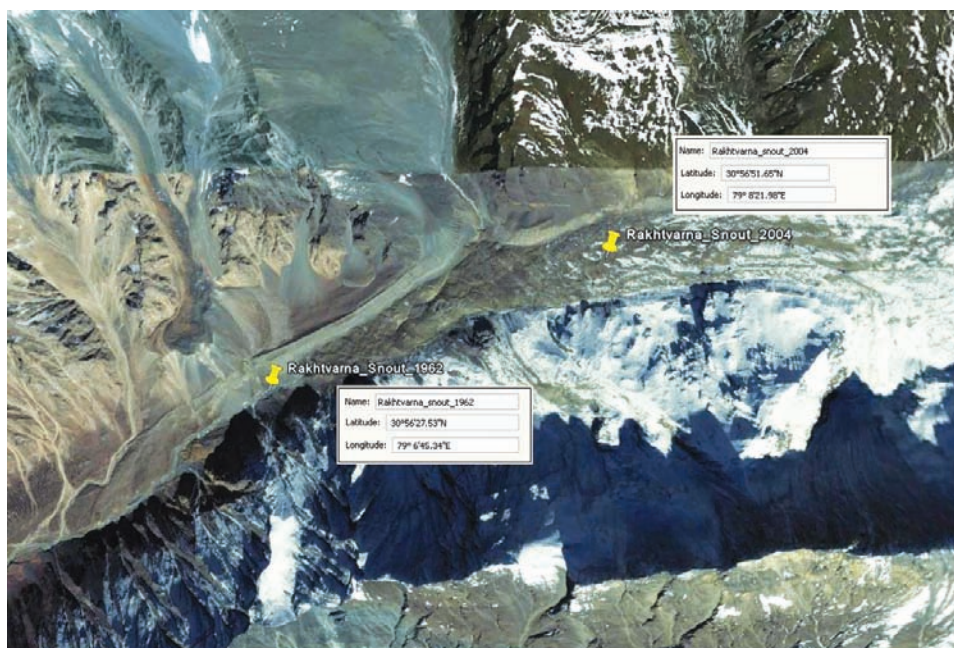


Plate-1.1.
Geographic position of Raktvarna (above) glacier snouts in 1962 and 2004.

(Source of Coordinates¹⁰:
image from Google Earth).

Plate-1.2.

Geographic position of Thelu glacier snouts in 1962 and 2004

(Source of Coordinates¹⁰:
image from Google Earth).

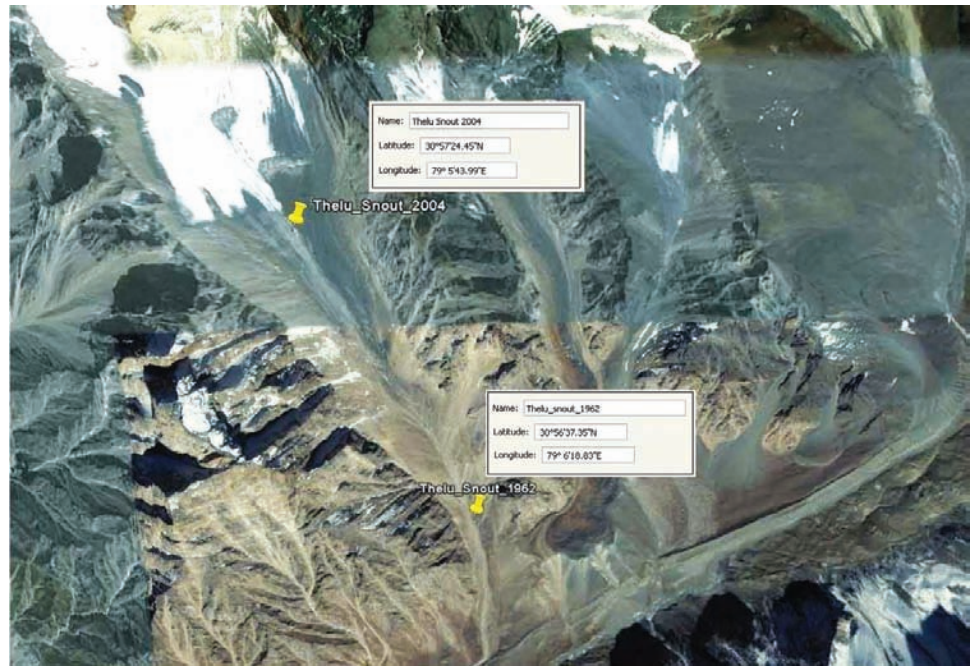


Plate-1.3.

Geographic position of snout of the Gangotri Glacier in 1935, 1971 and 2004

(Source of Coordinates¹³:
image from Google Earth).



The snow cover is depleting at different rate in different regions. In Colombia, “Since the end of the Small Ice Age (1850), the glacier regions of Colombia lost 80 per cent of their area, considering current climate change trends in Colombia, an analysis of this process suggests that the glaciers will disappear completely within the next century, as has already happened to other glaciers in the country”¹¹. According to Fagre¹², “Small alpine glaciers are rapidly disappearing in the Glacier MBR (Rocky Mountain USA). Historic data on recession have been produced that show over 72 per cent of the largest glaciers have disappeared over the past century. Geospatial modeling techniques were applied that suggest that all glaciers will disappear by 2030”.

1.3.3. Changes in Snow Period

Although studies are not yet available from the Uttarakhand region that due to global warming the snow period is changing but a study¹⁴ from Changbaishan Natural Reserve in the neighboring country China reports, “During the early 1970s, we observed that the snow period usually began in mid-September, ending in July of the following year. However, we now observe the snow period beginning in October and ending earlier; the period when snow is seen on the mountain summit has also diminished. Twenty years ago there were perennial scattered snow patches in the valleys throughout the year above 2300 m elevation. Today no snow patches are found during the hot summer months.” The situation may be similar in the Uttarakhand region but the documents or reports of such changes are not available.

1.3.4. Transformation of Glacial Fed Rivers

The mighty glacial fed rivers of Uttarakhand are gradually leading towards non-glacial fed rivers due to reduction in snow cover area and recession of glaciers. One of the major glacial fed rivers of the State, viz., the Saryu has been completely transformed into non-glacial river (Plate-1.4). Glacial fed rivers like the eastern. Ramganga and Pindar are on the top of the

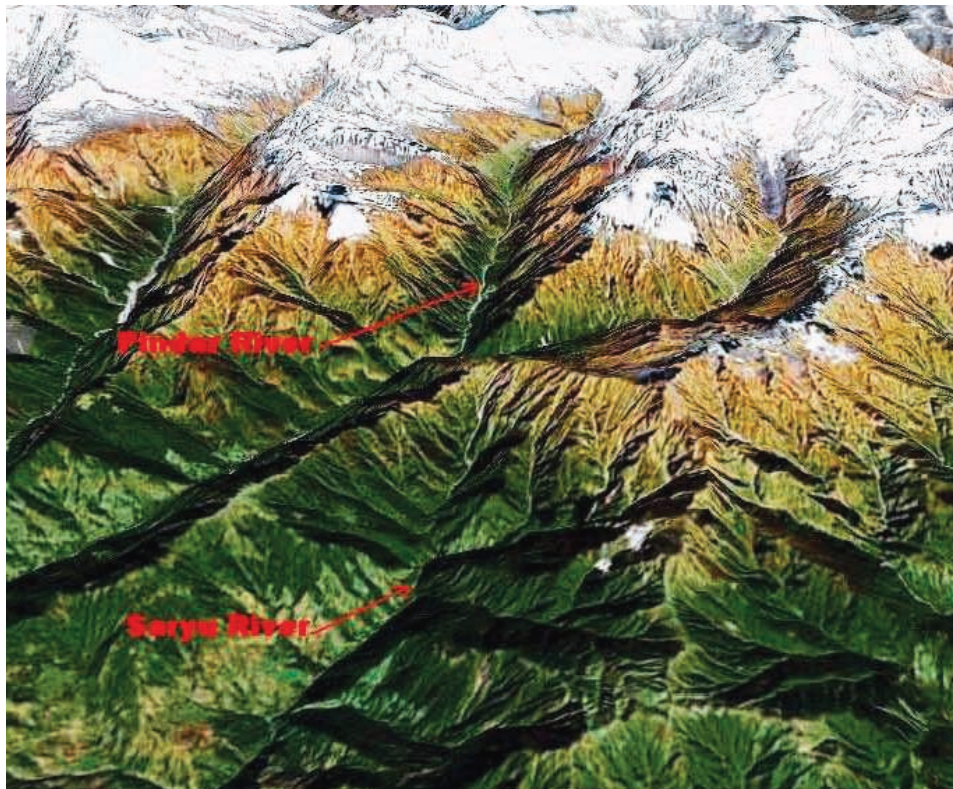


Plate-1.4.
Origin of Saryu River,
a non-glacial fed river

(image from Google Earth).

queue in the process of transformation of glacial fed to non-glacial fed rivers as the snow cover area in these watersheds remains only in 1.3% and 8.6%, respectively.

1.3.5. Development of Pro-Glacial Lakes

Signatures of development of pro-glacial lakes (Fig. 1.10 and 1.11) have started coming up in the region which is another sharp evidence of impact of global warming in the region. Apart from these two tiny pro-glacial lakes another important example of pro-glacial lake is the Gorikund located in the neighboring region Tibet (Plate-1.5). A brief account of these pro-glacial lakes is given below.

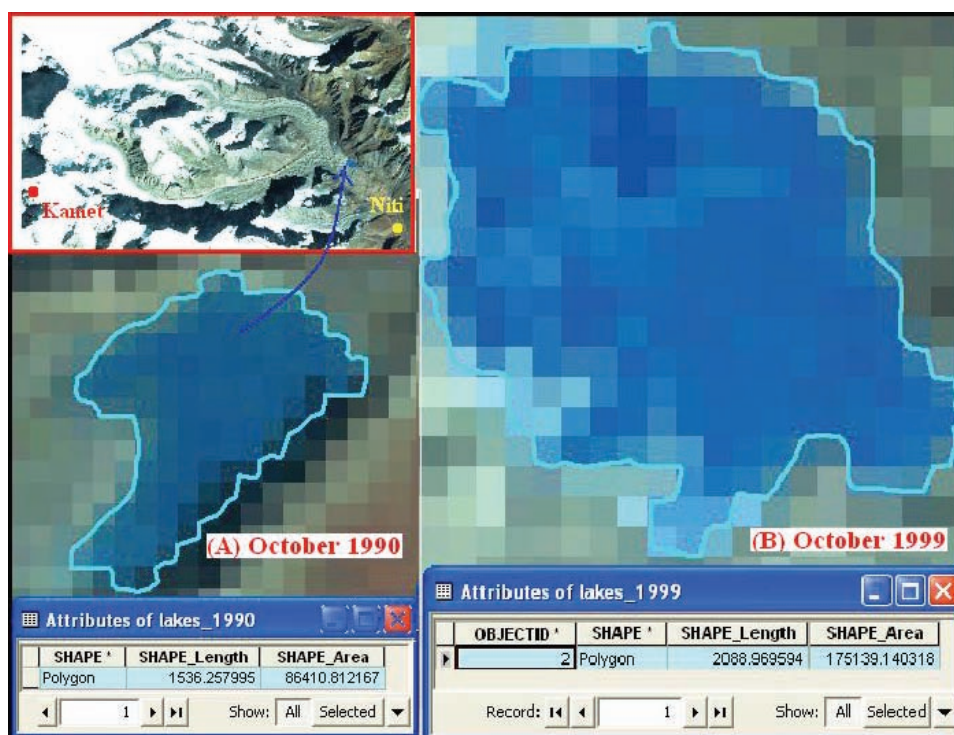
Example 1: Pro-Glacial Unnamed Lake in Dhauli Ganga Valley -North of the village Niti (in Dhauli Ganga Valley) in district Pithoragarh, a pro-glacial lake (30°54'4"N Latitude and 79°45'21" E Longitude) at the height of 4720m from m.s.l. has been developed at the mouth of the terminal moraine of the Kamet Glacier (Fig. 1.10A). Due to warming, the size of this lake is gradually increasing. In October 1990 the aerial extent of this lake was about 0.0864 km² which was found 1.1751 km² after 9 years, i.e., in October 1999 (Fig. 1.10B). During this period (1990-1999) the aerial extent of this lake has been increased about 0.09 km² at the rate of 0.01 km²/year.

Example 2: Pro-Glacial Unnamed Lake in the Bhagirathi Watershed -In the Bhagirathi watershed (31°16'12"N Latitude and 78°56'22"E Longitude) at an elevation of 4700m, a small new lake has been developed due to global warming which can be seen in 1999 image (Fig. 1.11B). The image (Fig. 1.11A) depicts that there was no lake at that place in 1990. In October 1999 the aerial extent of this lake was about 0.0254 km² which was found 0.031 km² after 11 years, i.e., in October 2010 (Fig. 1.11C). During this period (1999-2010) the aerial extent of the lake has increased about 0.0056 km².

Example-3: Melting of the Gorikund - "Situated on the eastern side of the Kailash peak is Gauri Kund (Plate-1.5, left),.....a small beautiful, oval-shaped lake about ¾ mile long and

Fig-1.10.

A pro-glacial lake developed by global warming at north of village Niti at the Kamet terminal moraine (based on Oct.1990 TM and Oct.1999 ETM data).



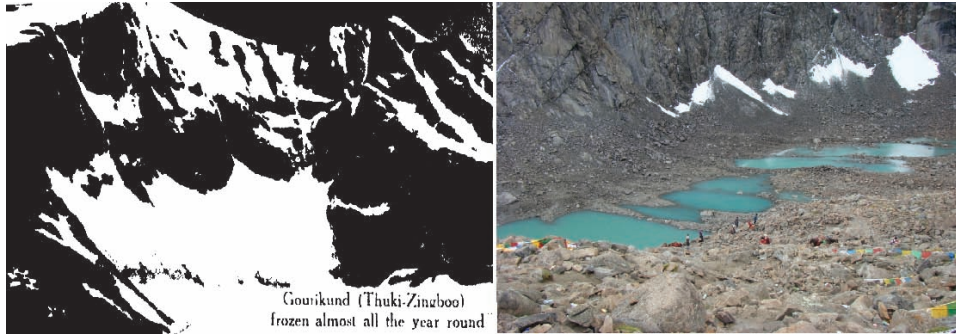


Plate-1.5.

Gorkund -Photo by Swami Purnanand 1946 (left); and Gorkund as witnessed in August 2010, Photo by Prof. N.C. Dhoundiyal (right).

½ mile broad covered with sheets of ice almost all the year round..... Pilgrims usually take bath in this lake, for doing so they often have to break ice on its surface; sometime the ice is so thick that they desperately hurl number of stones on it and yet cannot reach the water. No Tibetan has ever seen or heard this lake to have been completely free from ice" "But in 1946, 47 and 48 it completely melted away¹⁵. The present picture (Plate-1.5, right) of the glacial lake Gorkund depicts that the Gori Kund has been completely melted due to warming in the region.

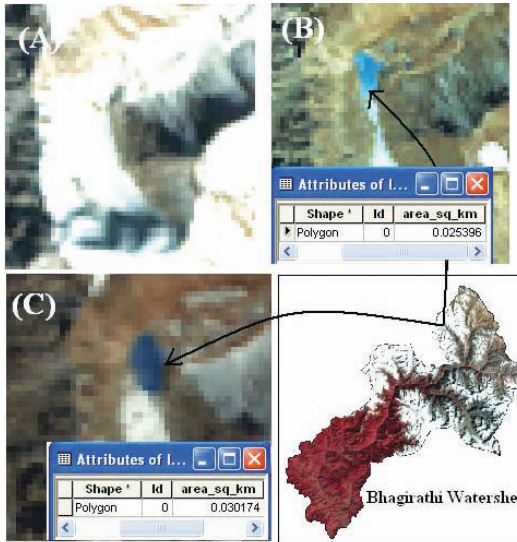


Fig-1.11.

A pro-glacial lake developed by global warming in the Bhagirathi watershed: (A) 1990 there was no lake, (B) in 1999 a tiny lake developed and (C) its size increased in 2010.

1.4. Biodiversity

The general effect of projected human –induced climate change is that the habitat of many species will move pole ward from their current locations. Disturbances can increase the rate of species loss and create opportunities for establishment of new species. The abrupt changes in climatic conditions in the mountainous part of the Himalaya are directly or indirectly affecting the vegetation development and regeneration of important species. Singh *et al.*¹⁶ studied the impact of climate change in the Himalayan region and reported that the Himalaya is warming more than the global average rate. Alpine ecosystems are particularly vulnerable to warming, as species occurring near the mountain tops will have no space for their upward march. The regeneration of many species is dependent on the monsoon rainfall especially the dominant sal, banj oak and telonj oak. The variation in such condition may adversely affect the regeneration and growth of these species. Long term data base is required on species composition, life cycle pattern of important species, monitoring of regeneration and species adaptation to climate change. This section attempts to understand the impact of climate change in shifting of few vegetation species, in particular, such as *Phoenix humilis*, *Euphorbia royleana* and *lichens*, and shifting of the vegetation line, in general in Uttarakhand.

1.4.1. Upward Shifting of Vegetation Species

Upward Shift of xerophytic Plant Royleana - The xerophytic plant *Euphorbia royleana* is gradually invading upward specifically in the tectonic valleys, for example, the Kakarighat valley in district Nainital (Plate-1.6). The upward growth of this plant is an indication of increasing aridity due to gradual temperature rise.

Plate-1.6. Development of xerophytic plant *Royleana* in the Kakarighat valley in district Nainital

(photo taken on 8th March 2011 by Naresh Pant).



Plate-1.7.

Palm trees developing their colony in the southern part of the Almora Town in the Kosi Valley

(image based on Google Earth, inset photo by Naresh Pant taken on 1st March 2010)



Plate-1.8.

Development of palm tree colonies near Kakarighat in district Nainital (photo taken by Naresh Pant on 8th March 2010)



Plate-1.9.

Oroxylum indicum (L.) Vent. with its capsules



Upward Shift of Palm Tree Colonies -The Palm tree (*Phoenix humilis*) a native flora is gradually invading towards higher altitude and has started developing colonies specifically on steep fault scarps constituted of highly deformed rocks having very thin and biologically poor soils. Such growing palm colonies are particularly discernible in the southern part of the Almora Town along a fault (Plate-1.7) and in Kakarighat valley near the South Almora Fault in district Nainital (Plate-1.8). Upward invasion of such colonies of palm trees is a sharp signature of aridity and beginning of the process of desertification in the region being accelerated by the climate change.

Upward Shift of *Oroxylum indicum* - Recent survey conducted by Joshi Pande¹⁷ reveals that *Oroxylum indicum* (L.) Vent. a medicinal plant (Plate-1.9), is gradually shifting towards higher altitude due to warming. As per studies of Atkinson¹⁸, Hooker¹⁹, Duthie²⁰ and Osmaston²¹, *O. indicum* (L.) Vent. grows in Kumaun region up to the height of about 914 m. Study conducted during 2010-2011 by Joshi Pandey reveals that a number of plants of *O. indicum* are growing above 914 m at many places in Kumaun and noticed its maximum altitude up to 1301 m at Sirauli and Kaseree (Gangolihat) in Kumaun Himalaya. A comparison of altitudinal range with that of Atkinson, Hooker, Duthie and Osmaston shows upward movement in order to approximately 387 m of *O. indicum* in Kumaun Himalaya within the last 83 years. This might be due to the climatic change in the Uttarakhand hills.

Upward Shift of lichens – Lichens are also gradually shifting towards higher elevation due to warming. In the Chopta-Tunganath landscape, which comes under Kedarnath wildlife sanctuary protected area, Upreti and Negi²² found distribution of 92 lichen species in between 2500 to 3500 m about two and half decade back, i.e., in 1988. Recent study in the same area conducted in 2009 by Kumar²³ has reported that lichens diversity has increased because apart from

already existing 92 lichens, 14 new species of lichens of lower altitude have come up in the Chota-Tungnath landscape area.

1.4.2. Shifting of Vegetation Line

Due to global warming shifting of vegetation line is an universal phenomenon in the alpine zones of the world. Recent study by Yang¹ in the neighboring country China has reported, "The greatest impact of climate warming observed in nature can be seen in the response of vegetation. Many annual observations and interviews with local people show that alpine *ermannii* birch has moved toward the tundra ecosystem over the last twenty years (Table-1.3)."

Watershed	Year	Average Height of Vegetation Line
Kuthiyangti	1972	4700m
	1990	5000m
	1999	5160m
	2010	5330m
Gori Ganga	1990	4900m
	1999	5040m
Dhaul Ganga E	1972	4600m
	1990	4880m
	1999	5040m
Ramganga E	1972	4200m
	1990	4580m
	1999	4670m
	2010	4840m
Pindar	1972	4200m
	1990	4500m
	1999	4700m
Dhaul Ganga W	1990	4980m
	1999	5190m
Alaknanda	1972	4600m
	1990	4980m
	1999	5200m
Mandakini	1972	4400m
	1990	4780m
	1999	4980m
Bhagirathi	1972	4620m
	1990	5000m
	2010	5350m
Yamuna	1972	3940m
	1990	4200m
	2010	4500m

Table-1.3.

Average height of vegetation line in different watersheds of Uttarakhand².

To examine above fact, the glacial fed river watersheds of the Uttarakhand state were studied using MSS October 1972, LANDSAT TM 15th and 21st October 1990, LANDSAT ETM+ 15th and 21st October 1999 and LANDSAT ETM+ 15th and 21st October 2010 satellite data. Vegetation lines uncovered by snow of different watersheds in different years were determined. The Average height of vegetation line was determined using Cartosat 1 data (Table-1.3) and then the amount and rate of shift of vegetation line in different watersheds were worked out (Table-1.4). A brief account of the status of vegetation line in the watershed is presented.

Table-1.4.
Amount and rate of vegetation line shift during different periods in different watersheds of Uttarakhand State².

Watershed	Years	Duration in Years	Shift of vegetation line	
			Amount	Rate in m/yr
Kuthiyangti	1972-1990	18	300m	16.69
	1990-1999	9	160m	17.78
	1999-2010	11	170m	15.45
	1972-2010	38	630m	16.58
Gori Ganga	1990-1999	9	140m	15.56
Dhaulti Ganga E	1972-1990	18	280m	15.56
	1990-1999	9	160m	17.78
	1972-1999	27	440m	16.30
Ramganga E	1972-1990	18	280m	16.67
	1990-1999	9	190m	21.11
	1999-2010	11	170m	15.45
	1972-2010	38	640m	16.84
Pindar	1972-1990	18	300m	16.67
	1990-1999	9	200m	22.22
	1972-1999	27	500m	18.52
Dhaulti Ganga W	1990-1999	9	210m	23.33
Alaknanda	1972-1990	18	380m	21.11
	1990-1999	9	220m	24.44
	1972-1999	27	600m	22.22
Mandakini	1972-1990	18	380m	21.11
	1990-1999	9	200m	22.22
	1972-1999	27	580m	21.48
Bhagirathi	1972-1990	18	380m	21.11
	1990-2010	20	350m	17.50
	1972-2010	38	730m	19.21
Yamuna	1972-1990	18	260m	14.74
	1990-2010	20	300m	15.00
	1972-2010	38	560m	14.74

The Kuthiyangti Watershed: Kuthiyangti is a northwest to south east flowing Tributary River of the Kali River system. The NDVI (Fig. 1.12) and Cartosat –1 data reveal that at present the average height of vegetation line in the Kuthiyangti watershed stands at 5330 m which was 5160 m in 1999, 5000 m in 1990 and 4700 m in 1972 (Table-1.3). These data suggest that the vegetation line in the watershed has been shifted about 630 m towards higher elevation within the last 38 years, i.e., between 1972 to 2010 (Fig. 1.13) at an average rate of 16.58 m/year (Table-1.4). During 1972-1990, 1990-1999 and 1999-2010 the rate of vegetation line shift in this watershed was at 16.69 m/year, 17.78 m/year and 15.45 m/year, respectively.

The Dhaulti Ganga E Watershed: For Dhaulti Ganga E, a tributary system of the Kali, three years data are available to examine the vegetation line shift. The results of these data reveal that the average height of vegetation line in the Dhaultiganga E watershed was at 5040 m in 1972, 4880 m in 1999 and 4600 m in 1990 (Table-1.3). These data indicate that the vegetation line uncovered by snow in the watershed has been shifted about 440 m towards higher elevation within the last 27 years (i.e. from 1972 to 1999) at an average rate of 16.30 m/year (Table-1.4). During 1972-1990 and 1990-1999, the rate of vegetation line shift in this watershed was found at 15.56 m/year and 17.78 m/year, respectively.

The Gori Ganga Watershed: For the Gori Ganga, a north to south flowing tributary of the Kali River, only two years data are available which reveal that the average height of vegetation

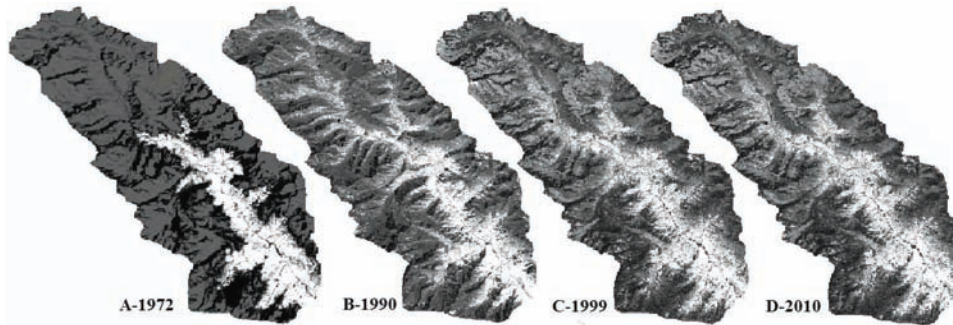


Fig-1.12.

NDVI in different years in the Kuthiyangti Watershed (based on MSS, LANDSAT TM and ETM+ data of October 1972, 15th October 1990, 15th October 1999 and 15th October 2010).

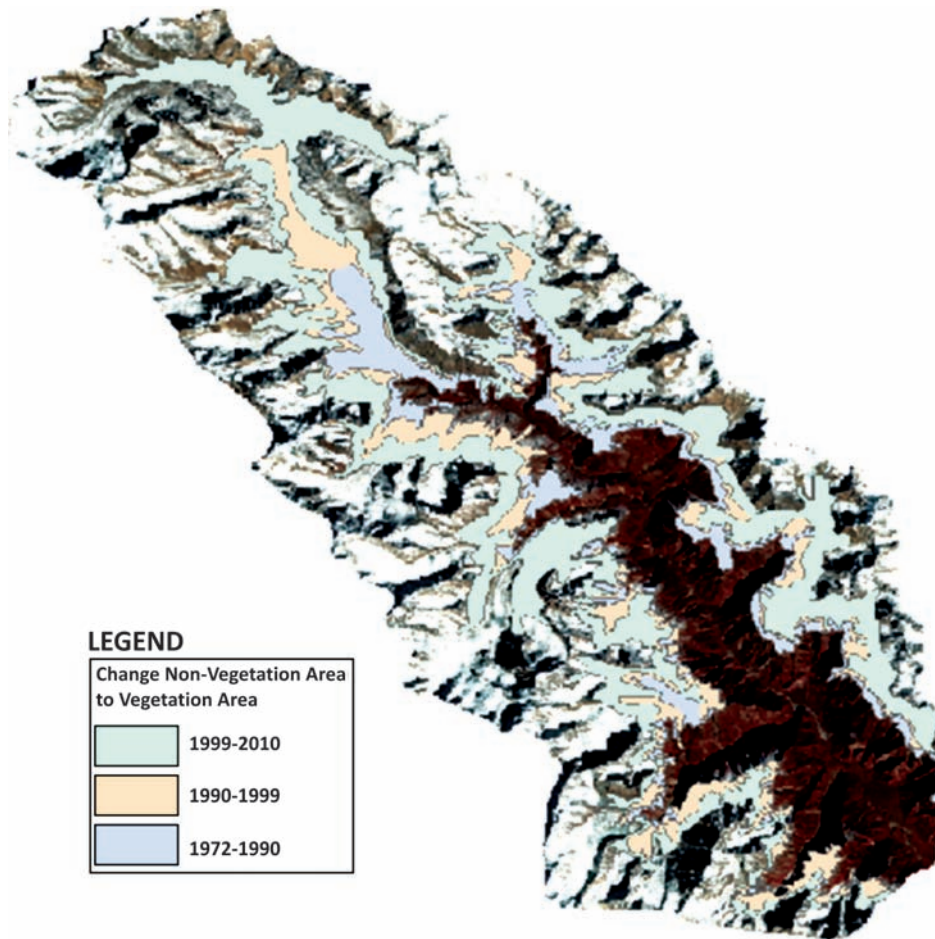


Fig-1.13.

Change from non-vegetative area to vegetative area in different periods in the Kuthiyangti watershed.

line in this watershed was 4900 m in 1990 which was shifted up to 5040 m till 1999 indicating a shift of about 140 m within the last 9 years at the rate of 15.56m/year (Table-1.4).

The E Ramganga Watershed: The Eastern Ramganga is a north to south flowing tributary of the Kali River system. At present the average height of vegetation line in the Ramganga stands at 4840 m which was at 4670 m in 1999, 4580 m in 1990 and 4200 m in 1972 (Table-1.3). Thus, the vegetation line in the watershed has shifted about 640 m towards higher elevation within the last 38 years (i.e. between 1972 to 2010) at an average rate of 16.84 m/year (Table-1.4). During 1972-1990, 1990-1999 and 1999-2010 the rate of



vegetation line shift in this watershed was at 16.67 m/year, 21.11 m/year and 15.45 m/year, respectively.

The Pindar Watershed: In the Pindar watershed, a east-west flowing tributary of the Ganga river, the average height of vegetation line was found at 4200 m in 1972, 4500 m in 1990 and, 4700 m in 1999 (Table-1.3). These data indicate that the vegetation line in the watershed has been shifted about 500 m towards higher elevation within the last 27 years (i.e. from 1972 to 1999) at an average rate of 18.52 m/year (Table-1.4). During 1972-1990 and 1990-1999, the rate of vegetation line shift in this watershed was found at 16.67 m/year and 22.22 m/year, respectively.

The Dhauli Ganga (W) Watershed: In the Dhauli Ganga West, a tributary of the Ganga River, the average height of vegetation line was 4980 m in 1990 which shifted up to 5190 m till 1999 indicating a shift of about 210 m within the last 9 years at the rate of 23.33 m/year (Table-1.4).

The Alakhnanda Watershed: In the Alakhnanda watershed, a tributary of the Ganga river, the average height of vegetation line was at 4600 m in 1972, 4980 m in 1990 and 5200 m in 1999 (Table-1.3). These data indicate that the vegetation line in the watershed has shifted about 600 m towards higher elevation within the last 27 years (i.e. from 1972 to 1999) at an average rate of 22.22 m/year (Table-1.4). During 1972-1990 and 1990-1999, the rate of vegetation line shift in this watershed was found at 16.67 m/year and 22.22 m/year, respectively.

The Mandakini Watershed: In the Mandakini watershed the average height of vegetation line was at 4400 m in 1972, 4780 m in 1990 and, 4980 m in 1999 (Table-1.3). In this watershed, the vegetation line has been shifted to 580 m towards higher elevation within the last 27 years (i.e. between 1972 to 1999) at an average rate of 21.48 m/year (Table-1.4). During 1972-1990 and 1990-1999, the rate of vegetation line shift in this watershed was found at 21.11 m/year and 22.22 m/year, respectively.

The Bhagirathi Watershed: In the Bhagirathi watershed, at present the average height of vegetation line stands at 5350 m which was at 5000 m in 1990 and at 4620 m in 1972 (Table-1.3). These data indicate that the vegetation line in the watershed has shifted to about 720 m towards higher elevation within the last 38 years (i.e. between 1972 to 2010) at an average rate of 19.21 m/year (Table-1.4). During 1972-1990 and 1990-2010, the rate of vegetation line shift in this watershed was found at 21.11 m/year and 17.50 m/year, respectively.

The Yamuna Watershed: In the Yamuna (including Tons) watershed at present the average height of vegetation line stands at 5000 m which was at 4200 m in 1990 and at 3940 m in 1972 (Table-1.3). These data suggest that the vegetation line in the watershed has been shifted to about 560 m towards higher elevation within the last 38 years (i.e. between 1972 to 2010) at an average rate of 14.74 m/year (Table-1.4). During 1972-1990 and 1990-2010, the rate of vegetation line shift in this watershed was found at 14.74 m/year and 15.0 m/year, respectively.

Status in Uttarakhand: The NDVI (Fig. 1.14) and Cartosat 1 based data reveal that in October 1990, the average height of the vegetation line in Uttarakhand was about 4770 m (Fig.1.15) which ranged between 4200 m in the Yamuna watershed to 5000 m in the Bhagirathi watershed. In October 1999, the average height of vegetation line was found at 4970 m (Fig. 1.15). These data suggest that the vegetation line has shifted on an average of 200 m

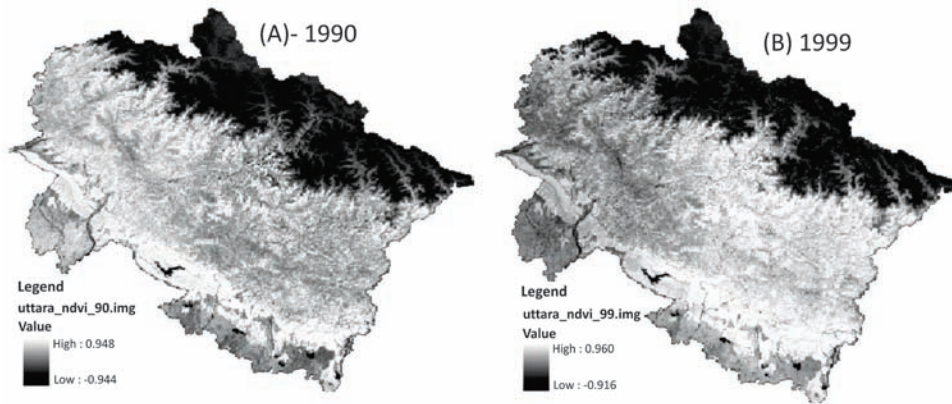


Fig-1.14.

NDVI in different years in Uttarakhand (based on TM and ETM+ data of 15th October 1990 and 15th October 1999).

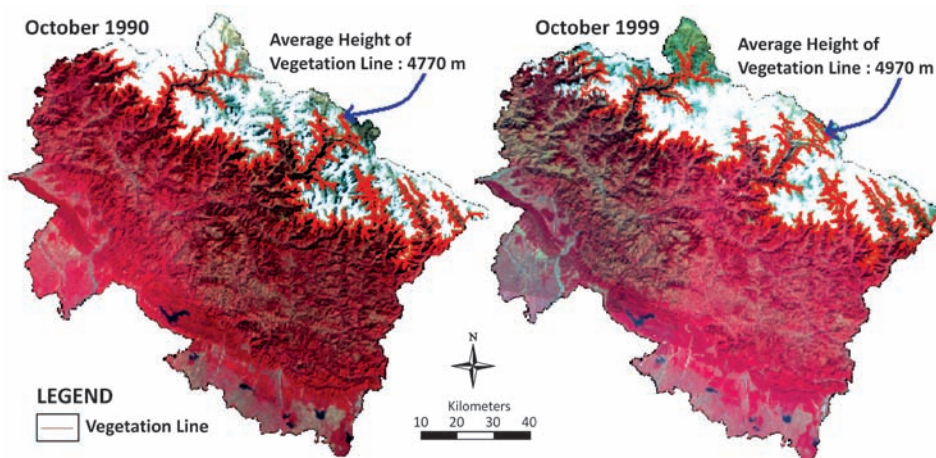


Fig-1.15.

Geographic Location of Vegetation line in Uttarakhand (based on 15th and 21st October 1990 LANDSAT TM data and 15th and 21st October 1999 LANDSAT ETM+ data²).

towards higher elevation within one decade (i.e. between 1990 to 1999) at an average rate of 22.22 m/year which varied between 15.56 m/yr in Gori Ganga to 24.44 m/yr in Alaknanda watershed (Table-1.4).

1.4.3. Phonological Changes

Variation in rainfall and temperature may lead to variations in phonological events of many species particularly the dominant oaks. The phonological changes in plant species have given clear signal that climate of the region is changing rapidly. Some of the incidences of phonological changes in plants are early ripping of kafal fruit with change in their taste and early flowering in *Rhododendron* trees²⁴. The phonological changes in tree and shrubs are also reported^{25,26,27,28}. These base line data would be helpful to predict the vegetation – climate change response and adaptation of species in such conditions. The phonological calendar should be developed especially for the evergreen species like oaks, *Rhododendron* and some important shrubs. Very few studies have been made on these aspects. Therefore, vegetation- climate change response should be investigated for the conservation and management of many important species of this region.

1.5. Streams and Rivers

Uttarakhand which lies on the highest water tower of the earth, viz., the Himalaya, is one of the most vulnerable regions of the world with respect to climate change genetic water stress. Evidences of shrinking of snow cover area, reduction in groundwater recharge, drying up of perennial streams and dwindling of summer flows in rivers have demonstrated

that climate change, and anthropogenic and technogenic activities²⁹ have alarmingly perturbed the hydrological cycle in Uttarakhand. Perturbation in hydrological cycle may result in adverse impact in near future on water availability for out-of-stream and in-stream uses in Uttarakhand. Out-of-stream uses include domestic, municipal, irrigation and industrial withdrawals. Water availability for withdrawal is a function of surface runoff and groundwater flow and aquifer storage. In near future, the goal of improved safe access to drinking water will be harder to achieve in non-glacial fed as well as glacial fed river watersheds in Uttarakhand because groundwater runoff has given clear signals of fast depletion as a result of anthropogenically accelerated climate change. People living in glacial fed river watersheds of Pindar, Alaknanda, Dhauri (W), Bhagirathi, Bhilangana, Yamuna and Kali which are experiencing decreasing snow storage in winter may be negatively affected by decreased river flows in the summer and winter seasons. In-stream uses of water include hydropower, navigation, fisheries and recreation. All these in-stream uses of water shall be adversely affected by global warming. The electricity production potential of hydropower plants will decrease considerably. Indications of this fact have started to come. Low summer flow conditions will restrict the recreation use of rivers such as rafting etc and shall adversely affect electricity production, and high flash floods may affect fishery production. If decreasing trend of precipitation continues, domestic and irrigation water demands, which dominate water use in throughout the region, would increase, and it may become very difficult to satisfy all demands.



1.5.1. Glacial Fed Streams and Rivers

Diminishing Regulatory Effect of Glaciers - There is a repeated common complaint of the local people that despite of melting of glaciers due to global warming why the discharge of the snow fed rivers is decreasing year by year? This is happening because of three reasons. Firstly, there has been significant reduction in the snow cover in the catchment areas of snow fed rivers since the last 3 to 4 decades and numbers of unnamed tiny glaciers have been completely disappeared which used to contribute water to the main rivers. Secondly, due to the decreasing length of time that snow remains on the mountain. Thirdly, in the glacial fed river system network, there are thousands of tributary streams which are groundwater fed and the groundwater storage has been drastically reduced due to change in rainfall behavior. Due to cumulative effect of these three factors, the flow of water into the major glacial fed rivers during the dry session has declined. Yang¹ through his study from Changbaishan Biosphere Reserve (China) has also reported that due to decreasing length of time that snow remains on the mountain, the flow of water into the river during the dry season has declined. Reduction in summer water discharge in glacial fed rivers is a warning for the production of hydroelectricity projects and also for irrigation facility for crops in hills as well as plains.

1.5.2. Non-Glacial Streams and Rivers

Reduction in Groundwater Recharge: The groundwater storage is a renewable resource which is recharged annually by the hydrological cycle through precipitation. Since the last three four decades drastic changes in the behavior of rainfall are noticed. The most important change is very rare or absence of snowfall events in the Lesser Himalayan region and complete absence of the popular geographic phenomenon, viz., *Satzhar*, i.e., low intensity rain of continuous seven days in mid of July when the *Herela* festival is celebrated. These two geographic phenomenon were responsible for sufficient recharge of the perched and deep groundwater storages in hills. Now in place of these two geographic phenomenon, the entire region is characterized by high intensity rain events and the frequent events of cloud burst followed by very high surface runoff resulting in drastic reduction in groundwater recharge.

Two hydrologic studies conducted under natural conditions in the Salla Raulela Pine Reserved Forest watershed (Fig. 1.16) and in the Dharpani Dhar spring sanctuary in Bhatkot Reserved Forest (Fig. 1.17) in the Central part of the Uttarakhand postulate the fact that due to change in rainfall behavior, groundwater recharge has been drastically reduced since the last three to four decades. A brief account of these case studies is presented below.

Case Study from the Salla Rautela Pine Watershed -The Salla Rautela (29° 35'19.37"N-29° 35'44.08"N Latitudes and 79° 33'3.25"E- 79° 35'20.66"E Longitudes), a non-glacial fed pine forest watershed in Syahi Devi Reserve Forest in Kumaun Lesser Himalaya (Fig. 1.16) was employed as a natural laboratory in 1992 to keep an eye on its hydrologic response to rain input³⁰. Attempts were made to maintain monitoring of these parameters till date^{31,32,33}. Water is tapped for drinking purpose from this watershed from two sites at the average rate of 0.07 l/sec, and 0.035 l/sec since 1970 and 1994, respectively. The site-I is a spring located at the height of 1840 m on northwestern middle part of the watershed and site-II is the stream itself at the height of 1800 m within the watershed. Table 1.5 contains the average discharge pattern and extreme conditions of water flow of the Salla Rautela stream. The extreme minimum water discharge records reveal that this stream was perennial in nature in 1992 when its minimum annual discharge rate was 0.038 l/sec. This minimum annual flow dropped down to 0.009 l/sec in 1999 and then since June 2000 this stream was transformed first time in its history to non-perennial stream (Fig.

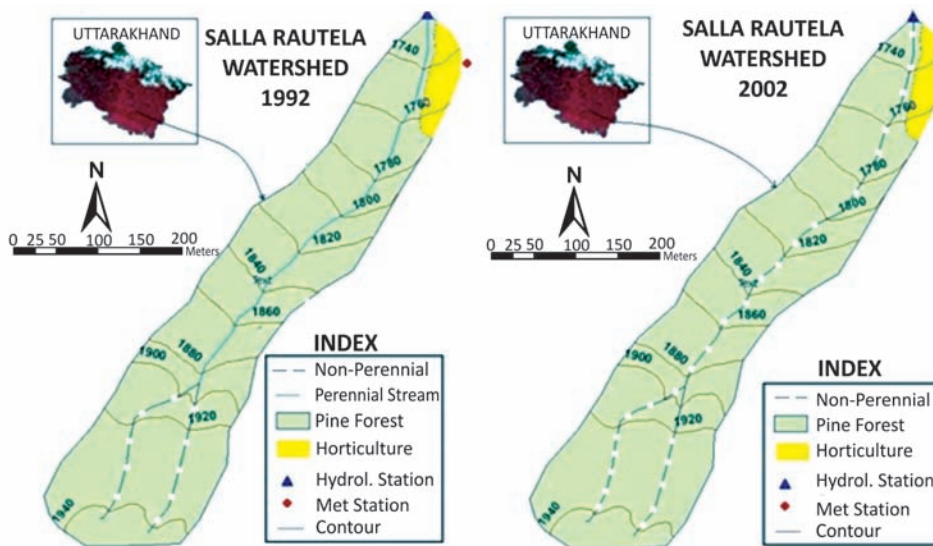


Fig-1.16.

The Salla Rautela watershed in the Syahi Devi Reserved Forest, district Almora drained by a perennial stream in 1992 (left). Since June 2000 this Salla Rautela stream has been transformed into non-perennial stream².

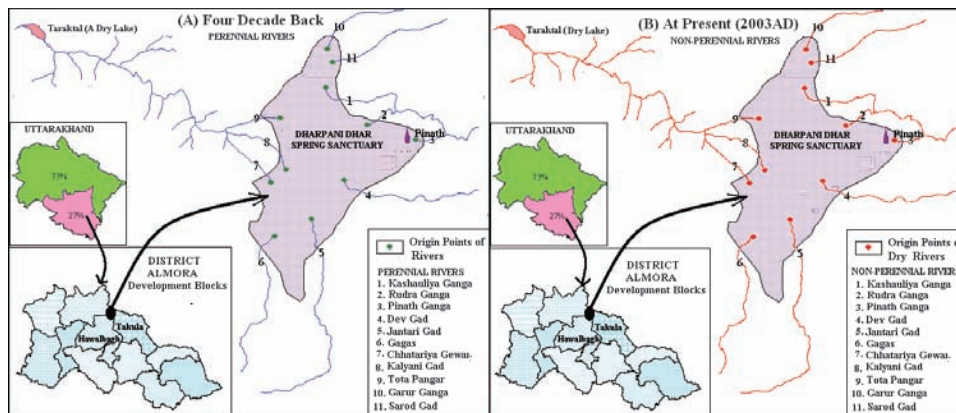


Fig-1.17.

The distribution of perennial streams in the Dharpani Dhar Reserve Forest about 4 decade back (A) based on Survey of India Topographic Map; and the present (2003 AD) condition of these streams (B), i.e., all streams have been transformed into non-perennial streams due to depletion of groundwater storage in the Dharpani Dhar aquifer³⁴.

1.16, right) when it was completely dried up for 64 days during summer season of that year. Since then the extreme minimum discharge of this stream was always found zero (Table-1.5). This is the sharp indicator that the groundwater level of the aquifer from which this stream originates, now goes below the origin point of this stream during summer due to low recharge of rainwater into the aquifer. The another important noticeable fact is increasing number of dry days of this stream which has reached up to 187 days, i.e., more than 6 months period in 2010 (Table 1.5 column 4). This is a hydrologic signal that ground water storage has gone drastically down in the watershed.

Table-1.5:
Characteristics of water discharge flow of the Salla Rautela Stream²

Year	Average Discharge (l/sec)	Ex. Max. Discharge (l/sec)	Ex. Min. Discharge (l/sec)	No of zero discharge days
1992	0.601	13.49	0.038	0
1993	5.481	361.51	0.022	0
1994	0.625	9.251	0.020	0
1995	0.310	7.35	0.018	0
1996	0.181	7.78	0.015	0
1997	1.420	25.89	0.012	0
1998	1.552	24.67	0.011	0
1999	0.340	10.12	0.009	0
2000	1.223	47.59	0.000	64
2001	0.316	22.29	0.000	79
2002	0.359	33.13	0.000	99
2003	0.228	27.93	0.000	88
2004	1.590	62.25	0.000	71
2005	3.817	119.4	0.000	140
2006	1.190	60.4	0.000	143
2007	1.350	155.2	0.000	120
2008	0.510	62.5	0.000	135
2009	0.321	8.21	0.000	175
2010	8.596	910.11	0.000	187

Case Study From Dharpani Dhar Spring Sanctuary - The Dharpani Dhar Spring Sanctuary (29°48'56"N to 29°53'33"N Latitudes and 79°30'4"E to 79°30'13"E Longitudes; area 17.23 km²), is located in the Bhatkot Reserved Forest, predominantly of pine trees in district Almora (Fig. 1.17). The groundwater storage (aquifer) of this hill gives birth to eleven perennial tributary streams (Fig. 1.17A) of three major rivers of Uttarakhand, i.e., Kosi, Gomati and Western Ramganga. The names of streams which originate from this spring sanctuary are - Kaushalya Ganga (or Kosi River), Rudra Ganga, Pinath Ganga, Dev Gad, Janatari Gad, Gagas River, Kalanyani Gad, Totapangar and Garur Ganga (or Gomati River). These rivers originate at 2000 m to 2240 m altitudes from the Dharpani Dhar Hill. The recent hydrometric survey shows that all these eleven perennial streams become dry during summer season due to depletion of groundwater in their aquifer (Fig. 1.17B). This study demonstrates that drying of perennial streams in forest system during summer is a sharp indicator that groundwater recharge has been reduced due to changes in amount and behavior of rainfall. The situation is similar in other forest systems of the region.

1.5.3. Transformation of Perennial Streams

Hydrologic studies of the Salla Rautela reserve forest watershed (Fig. 1.16) and the Dharpani Dhar reserved forest spring sanctuary (Fig. 1.17) demonstrate that due to reduction in groundwater recharge the perennial streams are being transformed from their perennial nature to the non-perennial nature. Thus, the perennial streams are being rapidly transformed into intermittent nature which are further gradually leading towards their ephemeral stage. This process of transformation of most of the perennial streams to seasonal streams is common phenomenon throughout the non-glacial river catchment areas even under the forest system. Apart from the streams, some of the mighty rivers and lifeline of major towns and villages have also transformed into seasonal rivers. For example the life line of Almora and Ranikhet towns, viz., the Kosi (Fig. 1.18 and 1.19) and the Gagas Rivers have been transformed into non-perennial rivers first time in their history of life since June 2003 and 2005, respectively.

1.5.4. Diminishing Length of Perennial Streams

The process of transformation of perennial streams into non-perennial streams is resulting in reduction of the total length of perennial stream network. A case study of the Kosi watershed in district Almora (Fig. 1.18A) reveals that about four decade back the total length of perennial streams in the watershed was about 225.6 km and at present their length is only 41.5 km (Fig.1.18B) due to the disappearance of perennial streams from the headwater regions. These data indicate that the perennial streams in the region are drying up at the rate of about 5.43 km/year in the Kosi watershed in district Almora due to anthropogenically accelerated processes of climate change. The process of diminishing length of perennial streams is relatively faster in the watersheds of non-glacial fed river catchments (Fig. 1.19) compared to the glacial fed river catchments because all the perennial streams of this region are groundwater fed.

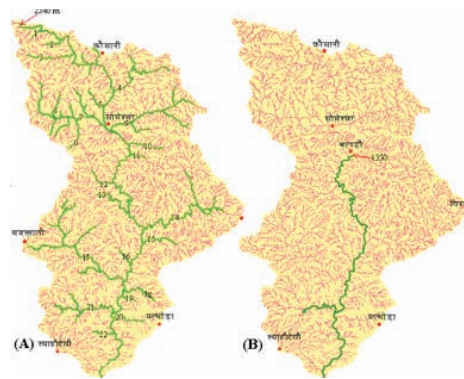


Fig-1.18.

Distribution of perennial streams (in green colour) and non-perennial streams (in red colour) in the Kosi watershed in district Almora; (A) about 40 years back total length of perennial streams was 225.6 km and (B) at present (2003 AD) it is only 41.5 km³⁵.

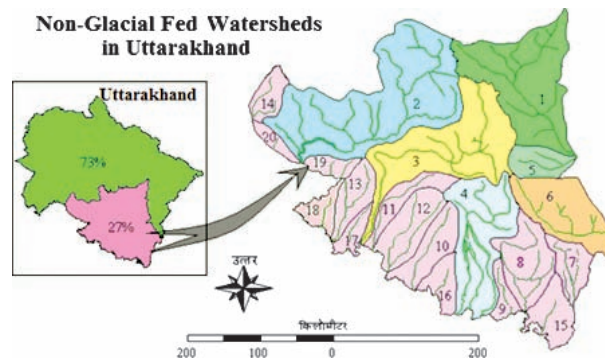


Fig-1.19.

Spatial distribution of non-glacial fed river watersheds in Uttarakhand³⁵;

1-Saryu, 2-W.Ramganga, 3-Kosi, 4-Gaula, 5-Panar, 6-Ladhiya, 7-Kirola, 8-Nandhor, 9-Dihowa, 10-Bhakar, 11-Dabka, 12-Baur, 13-Dhaila, 14-Kotdwar Stream, 15-Khatima Stream, 16-Rudrapur Stream, 17-Kashipur Stream, 18-Jaspur Stream, 19-Jhirana, 20-Barahapura.

1.5.5. Dwindling Summer Discharges of Rivers

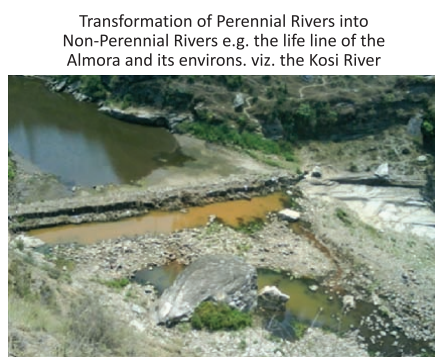
As it is evident from the Salla Rautela and Dharpani Dhar case studies that the perennial streams of reserved forest are being gradually transformed into non-perennial stream in the region. This is resulting not only in reduction in length of perennial streams network but also cumulatively affecting the summer discharges of major rivers. Gradually the major rivers are dwindling in summer season due to disappearance of perennial streams in massive scale in the headwater regions and partially by increasing rate of water extraction from river for different uses. Records of the last 18 years minimum water discharge of the Kosi River (Fig. 1.20) in district Almora postulate that the Kosi river dwindled very fast which was converted into non-perennial river on 22nd June 2009 (Fig. 1.20) about 50 m downstream of the Almora Pump house. Although no long term data of water discharge are yet available with UCCC but the point measurements of the Saryu, Panar, Western Ramganga and Kosi (Fig. 1.21) reveal that the summer flows of these non-glacial fed rivers is dwindling steadily due to anthropogenically accelerated climate change. The minimum summer flow of Saryu and Panar at their confluence, W.Ramganga at Marchula and Kosi at Mohan was 3324 l/sec, 251 l/sec, 2282 l/sec and 175 l/sec, respectively in June 2005. After three years, i.e., in June 2008, the minimum discharge of these rivers was found at 2431 l/sec, 175l /sec, 1928 l/sec and 1170 l/sec, respectively (Fig. 1.21).

1.5.6. Water Quality

Higher water temperature and variations in runoff due to climate change in geologically weak and ecologically fragile region like Uttarakhand may produce adverse changes in water quality. Lowering of the water levels in rivers and lakes will lead to the re-suspension of bottom sediments and liberating compounds, with negative effects on water supplies. Cloud burst or high intensity rainfall will lead to an increase in suspended solids (turbidity) due to soil erosion, and pollutants will be introduced. Higher surface water temperature will promote algal blooms and increase the bacteria and fungi content. This may lead to a bad odor and taste in chlorinated drinking water and the occurrence of toxins. Moreover, even with enhanced phosphorus removal in wastewater treatment plants, algal growth may increase with warming over the long term. Due to the high cost and the intermittent nature of algal blooms, water utilities will be unable to solve this with the available technology. Increasing nutrients and sediments due to higher runoff, coupled with lower water levels, will negatively affect water quality, possibly rendering a source unusable unless special treatment is introduced. Furthermore, higher water temperatures will enhance the transfer of volatile and semi-volatile compounds, e.g., ammonia, mercury, dioxins, pesticides from surface water bodies to the atmosphere.

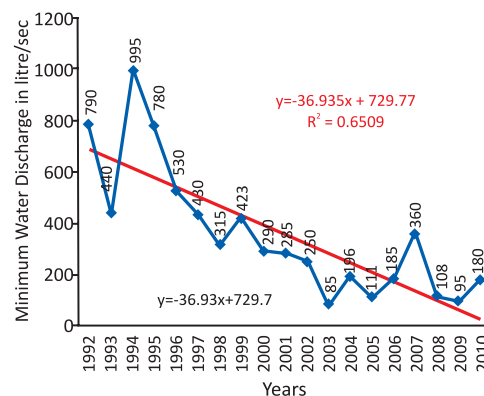
Fig-1.20.

Transformation of the lifeline of Almora, viz., the Kosi River in to non-perennial river (left) and its minimum annual water discharge rates near Almora pump house at Kosi³⁵.



22 June 2009, Discharge=0 litre/sec

Transformation of Perennial Rivers into Non-Perennial Rivers e.g. the life line of the Almora and its environs. viz. the Kosi River



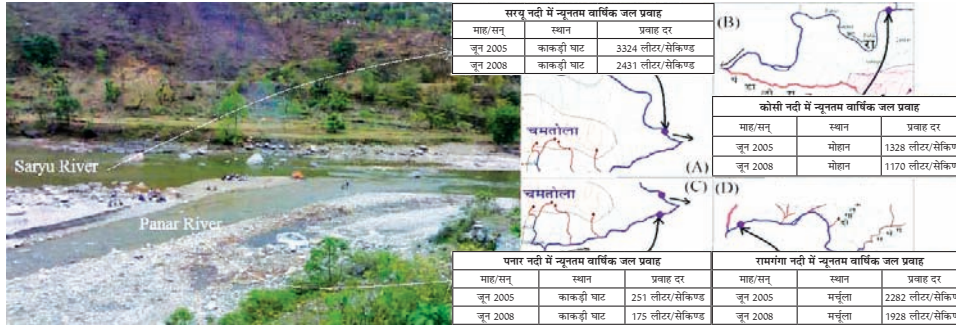


Fig-1.21. Minimum annual discharge rates of Saryu and Panar at their confluence, W. Ramganga at Marchula and Kisi at Mohan in 2005 and 2008.

In regions like Uttarakhand, where cloud burst and high intensity rainfall is expected to increase, pollutants (pesticides, organic matter, heavy metals etc) will be increasingly washed from soil to water bodies. Researches elsewhere have suggested that increasing water temperature affects the self-purification capacity of rivers by reducing the amount of oxygen that can be dissolved and use for biodegradation³⁶; increase nitrogen loads from rivers of up to 50% due to enhanced precipitation³⁷; numerous diseases linked to climate variations can be transmitted via water, either by drinking it or by consuming crops irrigated with polluted water. The presence of pathogens in water supplies has been related to extreme rainfall events^{38,39}; and in aquifers, a possible relation between virus content and extreme rainfall can be developed⁴⁰.

Higher water temperature and variations in runoff due to climate change are likely to produce adverse changes in water quality. Chemistry of water greatly depends upon the temperature. Although specific data is not yet available from Uttarakhand that how much the water quality is being or will be effected by temperature rise but a study of 54 ground water resources (i.e., springs and hand pumps) of district Almora carried out in 2007⁴¹ has demonstrated that the water quality parameters like pH, Dissolve Oxygen (DO), Total Dissolve Solids (TDS) (Fig. 1.22) and cations and anions concentrations have direct relationship with temperature. These base line data shall be useful to define the impact of climate change in water quality parameters (pH, TDS and DO) by re-examining these parameters in future.

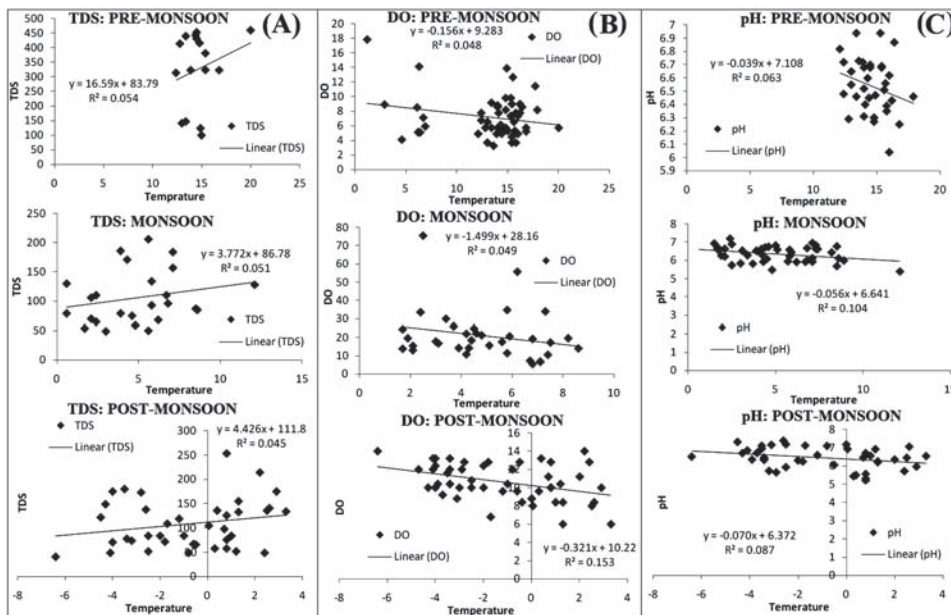


Fig-1.22. Variation in concentration of TDS (A), DO (B) and pH (C) with temperature, based on the study of 54 groundwater sources, i.e., springs and hand pumps carried out in 2007⁴¹.



1.6. Agriculture

1.6.1. Reduction in Crop Production

Recent study and surveys indicate that production of different crops is being affected by two major reasons related with climate change. First, delay in rainfall onset, and second, drying up of irrigation water sources, i.e., streams and rivers. A brief account of these two reasons is given below.

Delay Onset in Rainfall- According to Bhatt²⁴ due to changes in rainfall rhythm, delay in onset, rainfall during maturity period of crops and erratic behavior of rainfall have caused significant crop loss and delayed crop leads to yield reduction. Recent study advocates about 19.7% reduction in wheat, 48.5% in soybean, 28.6% in lentil, 45.2% in garden pea and 36.7% in pea production due to late shown caused by delayed onset of rain (Table-1.6). Early ripping of wheat crop (i.e. in March in place of April) due temperature rise is another sharp indicator of climate change.

Table-1.6.
Reduction in crop yield due to delay showing because of delay in rainfall²⁴.

Crop	Yield/Q/hect		Production in %
	Normal Shown	Late Shown	
Wheat	49.8	40.0	19.7
Soyabean	13.0	6.7	48.5
Lentil	19.2	13.7	28.6
Garden Pen	25.9	14.2	45.2
Field Pea	31.9	20.0	36.7

Drying up of Irrigation Water Sources- The production of crops from irrigated land is directly related with water available for irrigation. Due to very high intensity rainfall and incidences of cloudburst, a large part of the rain input runs off as overland flow from hills and a little part percolates deep into the rocks to recharge groundwater storage, consequently there is very little or no water flow in most of the hill streams during the summer season. Due to this reason the irrigation guls and canals remain dry due to lack of water. Hence, the irrigated land in hills is being transformed gradually into non-irrigated land by which the production of crops is drastically reducing year by year. Recent survey of paddy production (Table-1.7) from irrigated land conducted in one of the micro-watersheds of district Bageshwar, viz., the Mahogad (Fig. 1.23) reveals that due to lack of water for irrigation in the Mahogad stream during summer season, production of paddy crop has decreased considerably (Fig. 1.24) during the last decade. Table 1.7 suggests that in the Pokhari and Naogoan villages the production of paddy has reduced down to 53% while in villages Silingtoli and Ghirtoli it was found 52% and 41% less in 2010 as compared to 2001.

Table-1.7.
Production of paddy crop in villages of Mahogad Watershed in district Bageshwar².

Village	Area in hec	Production in Q/hect										Average Q/hect
		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	
Shilingtoli	7.70	66.12	69.10	65.72	59.80	65.32	51.62	46.48	41.68	40.90	34.93	54.17
Pokhari	6.90	61.72	69.31	62.08	60.55	58.28	46.97	43.24	60.31	39.01	33.00	53.45
Naogaon	12.26	64.32	67.64	64.29	59.53	63.40	50.48	45.04	39.88	39.33	34.52	52.84
Ghirtoli	14.17	59.78	62.85	57.21	50.21	40.22	44.51	29.98	29.95	20.29	24.95	41.99

1.6.2. Shifting of Horticulture Belts

Due to temperature rise, the temperate horticultural belts have started shifting towards higher altitude. Although such changes have yet not documented scientifically from Uttarakhand but in the neighboring state of Himachal Pradesh, it has been recently reported that the apple cultivation belt is shifting towards higher altitude⁴².

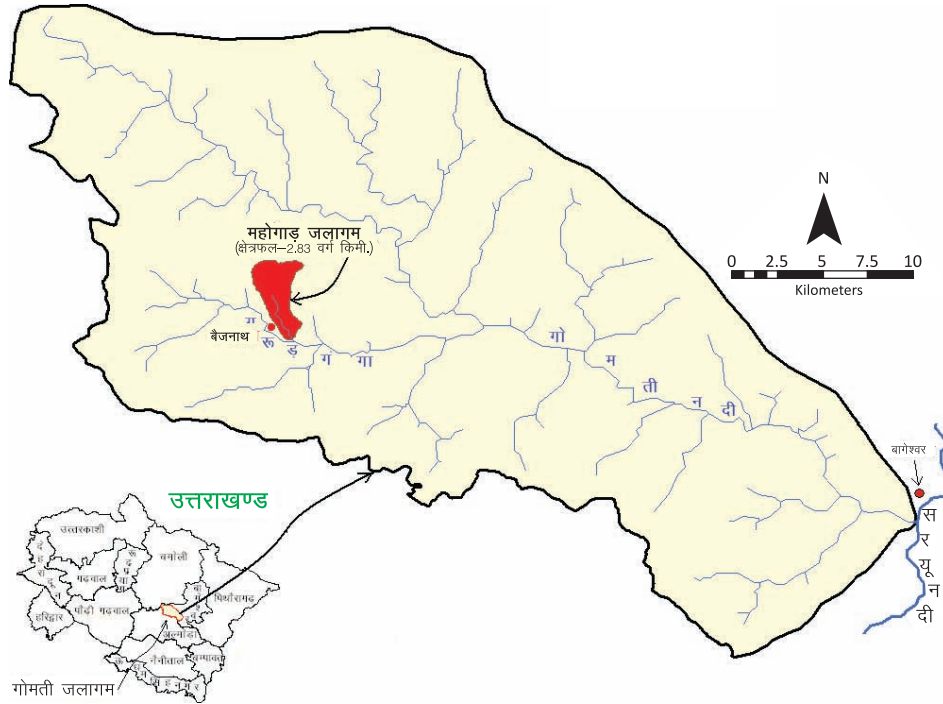


Fig-1.23.
Location map of the Gomti watershed, district Bageshwar

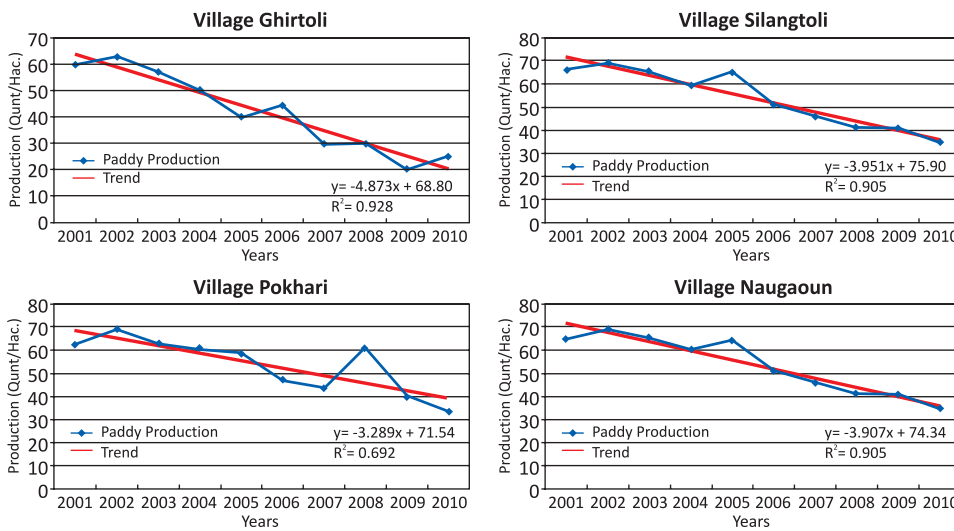


Fig-1.24.
Production and trend of paddy crop in the villages of the Mahogad watershed in district Bageshwar².

1.6.3. Reduction in Production of Fruits

Mango which is cultivated in many warm valleys of Uttarakhand such as Bageshwar and Bhikiasain is being threatened due to the impact of climate change. Apple is another important fruit whose production is highly vulnerable for climate change impact.

1.6.4. Impact on Pest Spectrum

Recent study of Bhatt²⁴ has indicated that climate change has started to impact the pest spectrum in hills. He has observed few incidents of Brown Plant Hopper in mid hills, increasing incidences of white grubs in May and June due to temperature increase, and positive effect of rice-leaf folder in the month of August due to change in rainfall rhythm.



1.7. Tourism

Climate is a major factor for tourists when choosing a destination both for tourists and tourism. Stakeholders are sensitive to fluctuations in the weather and climate. Likely effects of climate change on tourism vary widely according to location, including both direct and indirect efforts. In case of climate change in temperate and Alpine mountain in Uttarakhand seems to have shifted towards higher altitudes due to many forms of tourism. This might for instance, lead to more domestic tourism in higher altitudinal zones. Due to climate change, if winters turnout to be milder the gains are obvious. Tourism sector dependent on the availability of snow are among those most vulnerable to global warming. In summer, destinations which are already warm could become more uncomfortable. Tropical destinations might not suffer as much as from an increase in temperatures, since tourists might expect warm climate as long as indoor comfort is assured - with implications for greenhouse gas emissions. Extreme climate events, such as tropical events, could have substantial effects on tourist infrastructure and the economies. Indirect effects include changes in the availability of water and cost of space cooling, but at least as significant could be changes in landscape of areas of tourist interest, which could be positive or negative. Warmer climates open up the possibility of growing or extending exotic environment which could be considered by some tourists as positive. Draughts and extension of arid environment and the effects of extreme weather events might discourage tourists. One indirect factor of considerable importance is energy prices, which affect both the cost of providing comfort in tourist areas and the cost of travelling to them. The environmental context in which tourism will operate in the future involves considerable uncertainties. Nature based tourism is one of the booming industries in Uttarakhand, specially ski resorts, snow, hill, lake and valley, mountain and snow view resorts, wild life sanctuaries, waterfall picnic spots and ecotourism destinations which are likely vulnerable to climate change⁴³.

1.8. Health

Uttarakhand has complex climate environment. Climate change impacts show significant increase in respiratory-related diseases and hospitalization. Besides heat stress and respiratory distress from air quality, changes in temperature, precipitation and/or humidity effect environment for water-and vector-borne diseases and create conditions for disease outbreaks. Climate-change related exposures are likely to affect the health status of people particularly to those with low adaptive capacity, through: increase in malnutrition and consequent disorders, with implications for child growth and development; increase in deaths, disease and injury due to heat waves, floods, storms, fires and draughts; the increased burden of diarrheal diseases; in increased frequency of cardio - respiratory diseases due to higher concentrations of ground level ozone related to climate change; and the altered spatial distribution of some of infectious disease vectors. Climate change is expected to have some mixed effects, such as a decrease or increase in range and transmission potential of different diseases. Studies have shown that climate change is projected to bring some benefits, such as fewer deaths from cold exposure. Overall it is expected that these benefits will be outweighed by the negative health effects of rising temperatures. The balance of positive and negative health impacts will vary from one location to another, and will alter over time as temperatures continue to rise. Critically important will be factors that directly shape the health of populations such as education care, public health initiatives and infrastructure, and economic development.

Climate change is likely to alter social environment resulting in important impact on activities. The climate change may affect environment in three different ways. First, it provides a context for climate-sensitive human activities ranging from agriculture to tourism, For instance, rivers fed by rainfall enable irrigation and transportation and can enrich or damage landscape. Second, climate affect the cost of maintaining climate

controlled internal environments for human life and activity; clearly higher temperatures increase costs of cooling and reduce cost of heating. Third, climate interacts with other types of stresses on human systems, in some cases reducing stresses but in other cases exacerbating them. For example, draught or landslides caused by high intensity rain can contribute to rural urban migration, which combine with population growth, increases stress on urban infrastructures and socio-economic environment. In all of these ways, effects can be positive as well as negative; but extreme climate events and other abrupt changes tend to affect social environment more severely than gradual change, because they offer less time for adaptation, although gradual changes may also reach thresholds at which effects are notable⁴⁴.

1.9. Electricity

Due to climate change net electricity demand is very likely to change⁴⁵. Demand for air conditioning is highly likely to increase, whereas demand for heating is likely to decrease. Climate change is likely to affect both electricity use and electricity production. Some of the possible impacts of climate change in electricity in the mountainous region like Uttarakhand are rather obvious. Due to global warming less heat will be needed for industrial, commercial and residential buildings, but the cooling demands will increase with changes varying from the Outer to the Greater Himalayan region of the Uttarakhand state, and by season. The main source of cooling is electricity, while coal, oil, gas, biomass and electricity are used for space heating. Regions with substantial requirements for both cooling and heating could find the net annual electricity demand increase while demand for other heating energy sources decline. In addition to demand side impacts, electricity production is also likely to be affected by climate change. Policies for reducing greenhouse gas emission are required to increase the production of electricity⁴⁶. Limited studies on the impacts of climate change on the electricity sector suggest that this sector will be affected by climate change. In particular, South Asia (including India) is expected to account for one fifth of the world's total electricity consumption by the end of 21st century. An increase in the energy consumption of industry, residential and transport sector could be significant as population, urbanization and industrialization rise. It is likely that climate change will influence the pattern of change in electricity consumption that could have significant effects on CO₂ emission.



1.10. Industry Trade, Retail, Commerce and Human Settlements

The economy of Uttarakhand is diverse along with adverse geographical conditions ranging from the subsistence agriculture, allied activities and small concentration of industries. Other activities include traditional crafts and skills, casual labour, employment in the fruit processing industries, tea gardens and tourism. Corn, wheat, millet, barley, sugarcane, tea, oilseeds, and potatoes are some of the major crops. A wide variety of fruits are grown in the state. Gradually tourism has emerged as a major growth industry in the state ranging from eco-tourism, pilgrimages, adventure sports and mountain climbing are major attractions of the area. The state is gifted with rich ecosystem which is responsible for the tremendous biodiversity of the region. However, the State has undergone major changes in the last century because of global warming and climate change. The conditions range from a critical situation in the Himalayas of Sikkim, Uttarakhand, and Kashmir to a moderately serious situation in Bhutan and the Eastern Himalayas.

The industrial infrastructure in Uttarakhand is mainly concentrated in plains (Haridwar, Dehradun and Udham Singh Nagar). These areas accommodate a large chunk of rural out migrated population who mainly work there as semi-skilled and unskilled laborers. The other commercial activities include fruit production and processing, floriculture, tea-estates, tourism etc. All the commercial operations are vulnerable to climate change as the perishable commodities are most climate sensitive. Extreme climatic events will

adversely affect the productivity and sometimes as a consequence of frequent blockage of transportation routes the whole produce may get destroyed.

Vulnerability of industry, infrastructures and human settlements to climate change are generally greater in certain high risk locations, particularly in hill state like the Uttarakhand having fragile ecosystem, landslides and areas where economics are closely linked with climate-sensitive resources, such as agricultural and forest product industries, water demands and tourism. These vulnerabilities tend to be localized but are often large and growing. Industry includes manufacturing, transport, energy supply, and demand, mining, construction and related informal production activities. Climate change is almost certain to affect human settlements (urban and rural both) large and small, in a variety of significant ways. Settlements are important because they are where most of the population live, often in concentrations that imply vulnerabilities to location specific events and processes and, like industry and certain other sectors of concern, they are distinctive in the presence of physical capital (buildings, infrastructures) that may be slow to change. Case studies of larger settlements indicate that climate change is likely to increase heat stress in summers while reducing cold-weather stresses in winter. It is likely to change precipitation patterns and water availability, to lead to increase risk of extreme weather events, such as severe storms causing massive landslides and flooding.

Extreme weather events associated with climate change pose particular challenges to human settlements, because assets and populations are increasingly located in mountain slopes and other risk prone zones. Settlements within urban areas specifically in the hills are especially vulnerable, as they tend to be built on hazardous sites and to be susceptible to landslides and other climate related disasters. Several recent assessments have considered vulnerabilities of rapidly growing and/or large urban areas to climate change.

Possible impact on climate change on inter-regional trade is still rather speculative. Climate change could affect trade by reshaping regional comparative advantage related to general climate-related influences such as on agricultural production. Climate change may also disrupt transport activities that are important to national supplies and travellers as well as international trade. For instance, extreme events may temporarily close transport route and damage infrastructure critical to trade. Increases in the frequency and magnitude of extreme weather events could amplify the cost to transport companies and state authorities from closed roads, train/truck delays and cancellations and other interruptions of activities. It appears that there could be linkage between climate-change scenarios and different scales of trade scenarios, such as a number of regional and sub-regional free trade agreements, although research on this topic is lacking.

Climate change is likely to interact with and possibly exacerbate ongoing environmental change and environmental pressure in settlements. In region like the Uttarakhand, for example, mass wasting (i.e., landslides, rock fall, slumping and creeping) is expected to add to irreparable settlement damage. With growing urbanization and development of modern industries, air quality and hazard has become more salient issues in urban areas. How climate change might interact with these problems is not clear as a general rule, although temperature increases would be expected to aggravate the problems. In sum, settlements are vulnerable to impacts that can be exacerbated by direct climate changes. Retail and other commercial services have been often neglected in climate-change impact studies. Climate change has the potential to affect every link in supply chain, including the efficiency of the distribution network, the health and comfort of the workforce and pattern of consumption. In addition, climate change policies could raise industrial and transportation costs, alter trade patterns, and necessitate change in infrastructure and

design technology. As one example, distribution network of commercial activities would be affected in a variety of ways by changing rainy season road conditions and negatively affected by an increase in hazardous weather events. Strong wind can unbalance high sided vehicles on roads and bridges and may delay the passage of goods. Mountain infrastructure and distribution facilities are highly vulnerable for mass-wasting. Further climate variation creates short-term shifts in pattern of consumption within specific retail markets, such as the clothing and footwear market. Perishable commodities are one of the most climate-sensitive retail markets. It is possible that climate change will alter the sources and processing of agricultural produce, and climate change policies, e.g., a carbon tax or an emission offset payment, may further alter the geographical distribution of raw materials and product market⁴⁶.

1.11. Policy and Governance

To cope up with the impacts of climate change, there is an urgent need of new policies and some effective changes in our existing policies. Some of the vulnerable areas of policies which need urgent intervention are policy on forestry, water policy and policy on hydropower. A brief description of these policy areas is given in the following paragraphs⁴⁷.

1.11.1. Policy on Forestry

Recently, sixteenth session of Conference of Parties of United Nations Framework Convention on Climate Change (UNFCCC) was held at Cancun, Mexico. In this session, immense stress was given for adopting the scheme Reducing Emission from Deforestation and Forest Degradation (REDD+) and Enhancing the Carbon Stock in Developing Countries. Core idea behind underlying REDD+ is to make performance-based payments, that is, to pay forest owners and users to reduce emissions and increase removals. India is a party to REDD+. There is vast scope for attracting REDD+ scheme in Uttarakhand. Under the REDD+, Deforestation means forest area is reduced, Degradation means carbon density is reduced and Regeneration and Rehabilitation means carbon density is increased. The existing policies need urgent intervention in order to evolve a socially just and environmentally sustainable policy for the following sectors of the forestry, which at the same time may be eligible to attract REDD+ incentives in Uttarakhand. The forests can further be distributed in *van panchayats, protected areas, reserved forests and private tree cover* categories for the purposes of formulating policies.

1.11.2. Water Policy

One of the consequences of the climate change is the speedy depletion in water availability. In near future, the State is going to face water scarcity. In order to deal with the situation, intervention is needed in *groundwater policy, surface water policy, drinking water policy and irrigation water policy* sectors.

1.11.3. Policy on Hydropower

In International climate regime incentives under Clean Development Mechanism are provided. In the State, three private sector hydropower projects are receiving incentives and Uttarakhand Renewable Energy Development Agency (UREDA) has been enlisted for Clean Development Mechanism in UNFCCC in its 16th session held in Cancun, Mexico. A policy on hydropower is needed to be in tune with the international climate regimes in order to receive incentives of Clean Development Mechanism.

1.12. Towards Mitigation of Climate Change Impacts: The UCCC Efforts

UCCC aims to develop action projects for mitigation of climate change impacts. For this purpose UCCC has employed the Mahogad (Fig. 1.23) - a representative watershed of

the Lesser Himalayan non-glaciated watersheds, as its first natural field laboratory. The Mahogad is a non-glacial fed perennial tributary of Gomati river which joins Saryu at Bageshwar. It provides drinking and irrigation water to the highly fertile land of clay soil of Pokhari, Naogaon, Ghirtoli, Shilingtoli villages. Since June 2010, the Mahogad river has been transformed into non-perennial river by which there has become water scarcity for irrigation as well as drinking water in the surrounding villages. Study indicates that due to depletion of water resources, production of paddy in the villages of Mahogad watershed (Fig. 1.24) has gone drastically down (50% to 70%) during the last one decade. Changes in the resource pattern occurred during the last 5 decades in the villages of the Mahogad watershed were studied in detailed on Cadastral maps using GIS and GPS technologies. For example, figure 1.25 and 1.26 depict the resource pattern in one of the villages of the Mahogad watershed, viz., Naogaun about 5 decade back and at present. These resource maps of village Naogaun reveal that the water resources have depleted drastically and the large part of irrigated land of the village has been converted into non-irrigated land generating problem of agriculture and livelihood sustenance in the village. The condition of other villages of the Mahogad watershed is also similar to the Naogaun village.

For mitigation of climate change impacts, the most important work to be done is regeneration of drying and dead rivers in the non-glacial fed watersheds through both, mechanical and biological treatment measures of groundwater augmentation. This work cannot be done in isolation neither by the scientists and villagers nor by the government alone. It needs a coordinated action programme of scientists, villagers and government

Fig-1.25.

Status of resources during 1958-59 in one of the villages of Mahogad watershed, viz, Naogaun, Block - Garud, District Bageshwar (prepared through GIS and based on Cadastral Maps)

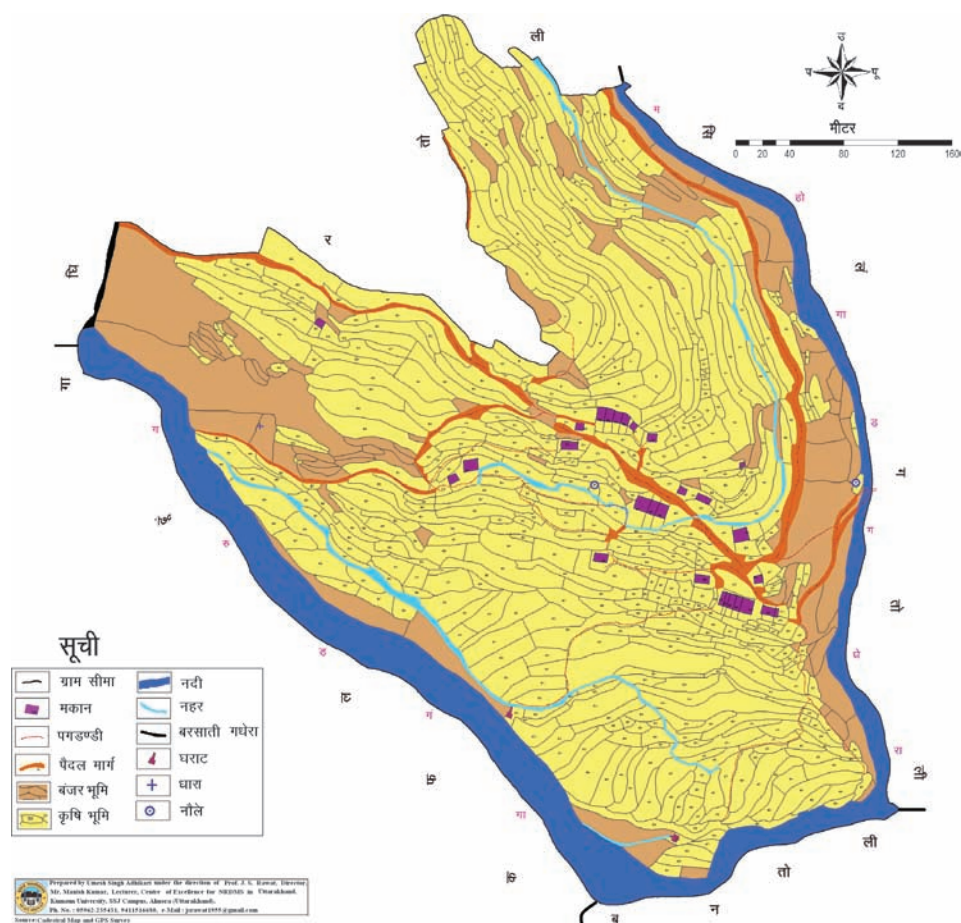




Plate-1.10.
Participants (Scientists/villagers/
Officers of Government
Departments) of UCCC workshop
organized at village Naogoun
on 7th December 2011.

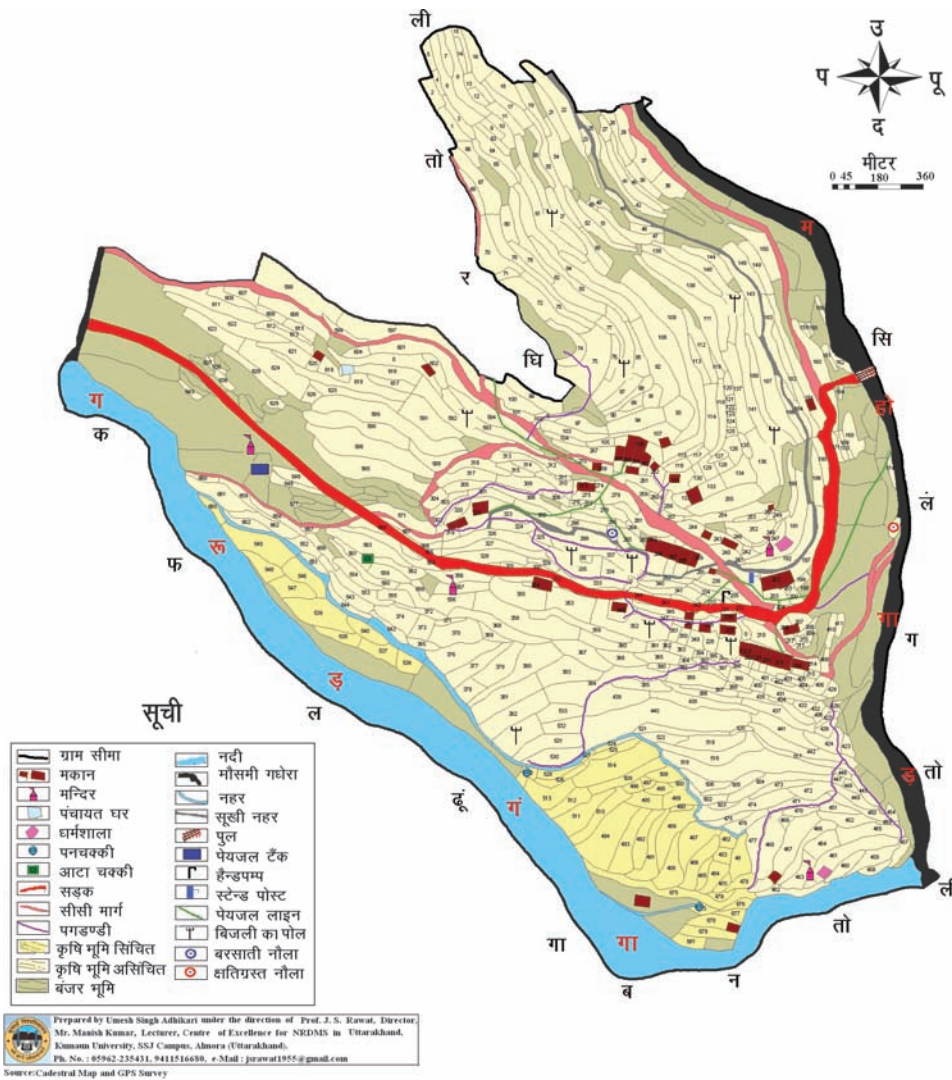
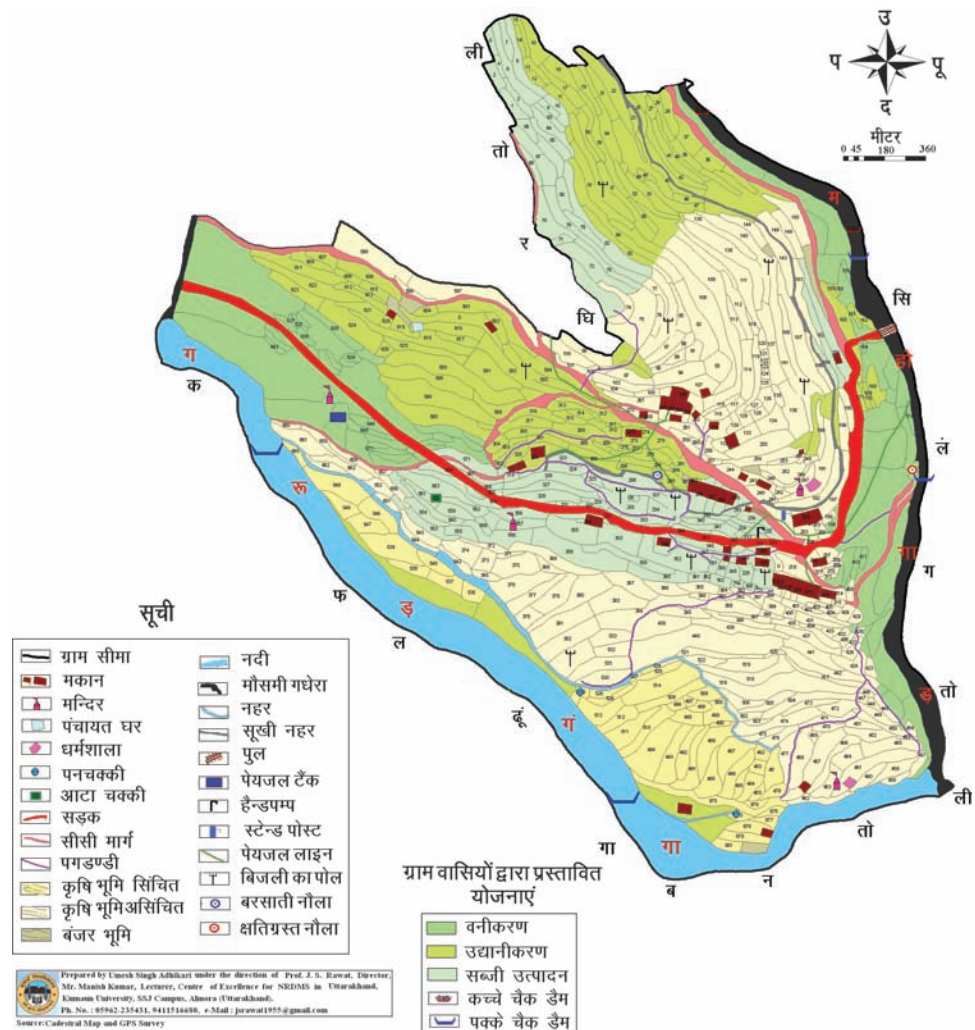


Fig-1.26.
Status of present resources
(2012) in one of the villages
of Mahogad watershed, viz,
Naogaun, Block - Garud, District
Bageshwar

departments. For developing a coordinated action plan for mitigation of climate change impacts in the Mahogad watershed, the UCCC organized a one day workshop at village Naogoun in the Mahogad watershed on 7th December 2011 in which 110 (i.e., 13 scientists, 74 villagers and 33 government officials) participants actively participated in the workshop (Plate-1.10).

After discussions, a detail action plan for mitigation of climate change impacts was worked out in this workshop⁴⁸. Past (Fig. 1.25) and present (Fig. 1.26) resources pattern of the villages was worked out. Two types of action plan were developed in the workshop. First, at village level in which development plans of each village were drawn by the villagers (Fig. 1.27) in case of the Naogaun village, and second watershed level, in which sites and area were identified for various mechanical and biological treatments for groundwater augmentation to regenerate dead and dying rivers. Fig. 1.28 depict the proposed sites/areas for Mahogad watershed treatment through the concerned government departments involving villagers and scientists advices. The implementation work of the Mahogad watershed action project is in progress through different government departments and the villagers. It is hoped that within next 3-4 years we shall have a concrete model for mitigation of climate change impacts in the highly fragile ecosystem and very sensitive environmental systems in Uttarakhand.

Fig-1.27. Proposed development plans (2012) of village Naogaun proposed by the villagers for sustenance of water, agriculture and livelihood.



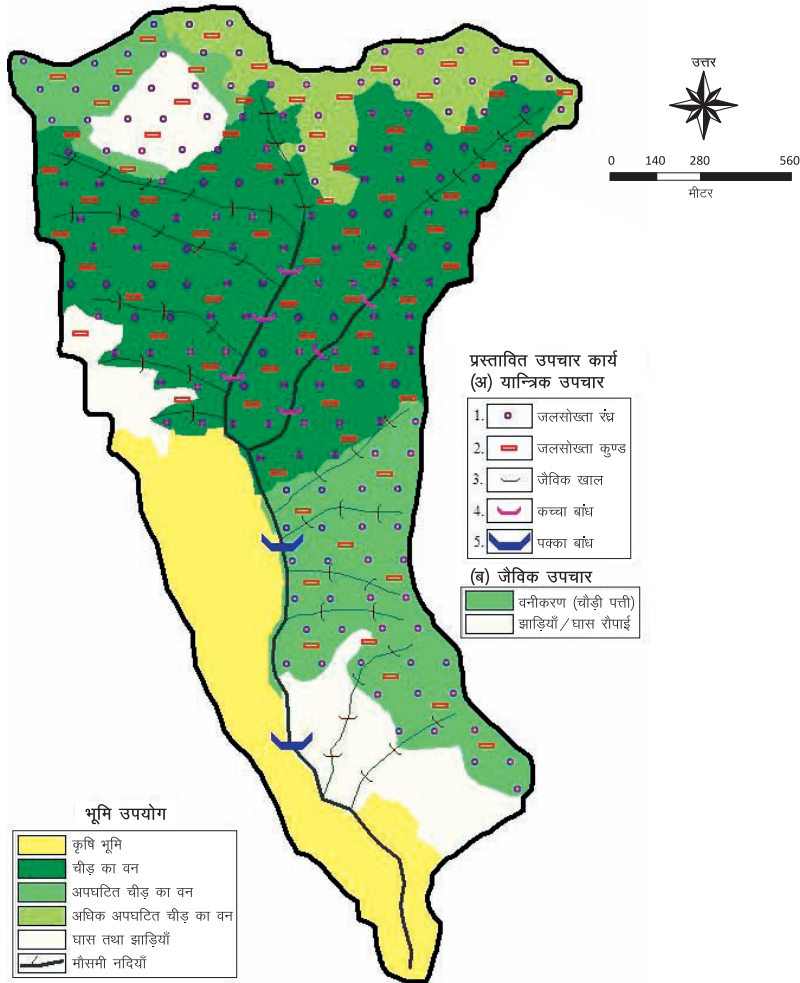


Fig-1.28.

Proposed sites/areas for mechanical and biological treatments in the Mahogad watershed for regeneration of dead/dying rivers of the through groundwater augmentation for sustenance of water, agriculture and livelihood.

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