J. Indian Water Resour. Soc.,
Vol 37, No. 3, July, 2017

ROLE OF CLIMATE CHANGE AND ANTHROPOGENIC ACTIVITIES IN 2013 FLOOD DISASTER OF UTTARAKHAND

M. L. Kansal[1] and Sandeep Shukla[2]

ABSTRACT

Himalayas are experiencing climate change at an unprecedented rate. This has contributed to the increased incidents of flash floods, landslides, Glacier Lake Outburst Floods (GLOFs). In the year 2013, during June 16-17, heavy rainfall followed by landslides and glacier movement led to heavy flood in the state of Uttarakhand. This flood affected more than 100,000 people in the state and more than 10,000 people were found either missing or dead in the state. More than 250 villages got severely affected. Besides the heavy loss of life, there was heavy damage to various infrastructures. The maximum damage was in Kedarnath valley, which is one of the four famous centers (Char Dhams) of spiritual faith of Hindu Mythology. It is felt that increase in anthropogenic activities and increased emissions of greenhouse gases (GHGs) have resulted in overall change of Himalayan climate. Such change in climate during the last few years has directly or indirectly compounded the risk of such disaster. This study discusses the role of climate change and anthropogenic activities on the occurrence of 2013 flood in the state of Uttarakhand. Further, it also suggests the short and long term measures which can be adopted to prevent and mitigate of such events in the future.

Keywords: *Flood disaster, climate change, anthropogenic activity.*

INTRODUCTION

Mountainous region of Uttarakhand state in India is inherently vulnerable to various type of disasters like high intensity rainfall, cloud bursts, land slide, flash floods, and earthquakes. During June 16-17, 2013, torrential rainfall and devastating floods hit the state when Hindu devotees were visiting Uttarakhand in huge numbers for worship at four holy places called "Char Dham", namely, Gangotri, Kedarnath, Yamunotri and Badrinath. All these centres are located in higher regions of the Himalaya and have tough hilly terrain with single route. In 2013, the monsoon reached Uttarakhand almost two weeks earlier than normal which resulted in cloud bursts and very heavy rainfall in several parts of the higher reaches of the state. Further, the water surge was caused by a breach in the boundary of Chorabari Lake due to heavy rainfall on the upstream. This resulted in the release of huge volume of water along with large boulders, devastating the towns of Kedarnath, Rambara, Gaurikund and others in its wake. The Heavy rains started on June 14, 2013 causing floods and landslides. This led to massive destructions of houses and roads in Rudraparyag, Uttarkashi and Chamoli districts on the way to the Himalayan shrines. Bridges collapsed and roads got destroyed. More disturbing was that a large number of people died. Govt. officials admitted that it is not possible to know the exact number of deaths, but it is feared that more than 10,000 people died. Rescue operation was carried out through areal route. But aerial route also was a difficult choice due to bad weather. Consequently, a large number of people lost their lives due to non-availability of basic infrastructure to survive. Though parts of other states like Himachal Pradesh, Haryana, Delhi, and Uttar Pradesh in India, and some region of Western Nepal, and Western Tibet also experienced heavy rainfall, but the major damage took place in Uttarakhand. As reported by the Indian Meteorological Department (IMD) (http://www.imd.gov.in/Welcome%20To%20IMD/Welcome.php), the three districts of Uttarakhand namely Rudraprayag, Uttarkashi, and Chamoli (where these four pilgrimage sites are located) received 366, 375, and 317 mm of rainfall, respectively, during June13-19, 2013. On June 16-17, 2013, a heavy rainfall of about 350 mm took place in the Kedar valley besides the intermittent rainfall before and after this event. Authorities described the calamity as a "Himalayan Tsunami". Natural disaster involving Himalayan mountains, rivers, forest, glacier and people in an area of more than 38,000 sq km is bound to be complex.

Geologically, Uttarakhand is located in a fragile and in the world's youngest mountain range. It is inherently vulnerable to various kinds of disasters, such as high intensity rainfall, cloudburst, landslide, flash floods and earthquakes (Jain et al, 2013). Its geology is ridden with numerous fault lines. Climate change is increasing the frequency of high intensity rainfall including cloud burst and flash flood, Glacial lake outburst flood along with landslides. The ill-fated tragedy of 2013 in Kedarnath occurred due to a combination of several events. Under such scenario, the development projects need to take such extreme conditions in to account and strive to reduce the risk.

Since the inception of the Uttarakhand state in 2000, the state is on a path of massive growth of various types of development, and reality of its vulnerabilities is generally ignored. Although heavy rainfall has wreaked havoc in the region due fragile nature of the Himalayan range and poor soil stability in its steep slopes, but the issue of warming up of the Himalayas cannot be ignored. It is higher than the global average of 0.74 ˚C over the last 100 years (IPCC, 2007) which is about 2-3 times higher than global average. This has increased the incidents of flash floods, GLOFs, landslides and related disasters. The Uttarakhand disaster has highlighted the changed behavior of monsoon and increase in anthropogenic activity over the last few years in this area that has compounded the scale of the disaster. The state is witnessing unprecedented development of Hydel Projects along its rivers, mainly in Alaknanda, Bhagirathi and their tributaries as well as in Ganga, Gori Ganga and Kali Ganga etc. As per one estimate, there are about 680 dams in various stages of planning, construction and commissioning in the state of Uttarakhand. This study highlights the role of climate change

1. *Professor[1] and Research Scholar[2]*
Department of Water Resources Development & Management,
Indian Institute of Technology, Roorkee (Uttarakhand)
e.mail: mitthan@gmail.com

Manuscript No.: 1452

and anthropogenic activities on the occurrence of 2013 flood disaster in the state of Uttarakhand. Further, it also suggests the short and long term measures which can be adopted to prevent and mitigate of such events in the future.

DESCRIPTION OF STUDY AREA

Climate of Uttarakhand:

Uttarakhand has broad climatic zone which varies with the raise in the elevation. The various climatic zones of Uttarakhand are given below:

- Warm Tropical region : < 600 m
- Cold Tropical-Sub Tropical region: 600-1200 m
- Warm Temperate region : 1200-1800 m
- Cool Temperate region : 1800-2400 m
- The Cold region : 2400-3000 m
- The Alpine region : 3000-4000 m
- The Glacial region: > 4000 m.

Temperature decreases with increasing altitude by a normal lapse rate of 0.65 degrees centigrade for each 100 m of altitude. Temperature zones range from very hot in Tarai-Bhabhar to extremely cold zone of the higher Himalayas. Mean monthly temperature with respect to altitude is given below:

- Up to 300 m: 11.0 °C (December) to 30.2 °C (August)
- 300-1600 m: 9.1 °C (January) to 22.0 °C (June and July)
- 1600-1700 m: 6.6 °C (January) to 22.2 °C (August)
- 1700-1950 m: 8.5 °C (January) to 21.4 °C (May)

Nearly 25% of the state is under snow cover at the end of winter season, which reduces to 21% at the end of monsoon season. Six districts of the state have snow cover, out of which Uttarkashi and Pithoragarh districts have the maximum snow cover. The snow cover area is 41% of the total geographical area of six districts for the month of April while it is 34.7% for the month of October.

Location

Uttarakhand is located in the northwestern part of India (28°4' to 31°27'N & 77°34' to 81°2' E). The severely affected areas of the state were the Kedar velley and the Kedarnath temple town. Kedarnath is located approximately 268 km from Dehradun in Uttarakhand in the western fringe of the Central Himalaya (79°4'1"E, 30°44'4"N) close to the source of the Mandakini river at a height of 3,583 m (http://en.wikipedia.org/wiki/Kedarnath). The Mandakini river is a tributary of Alaknanda river (Fig. 1). The temple site is

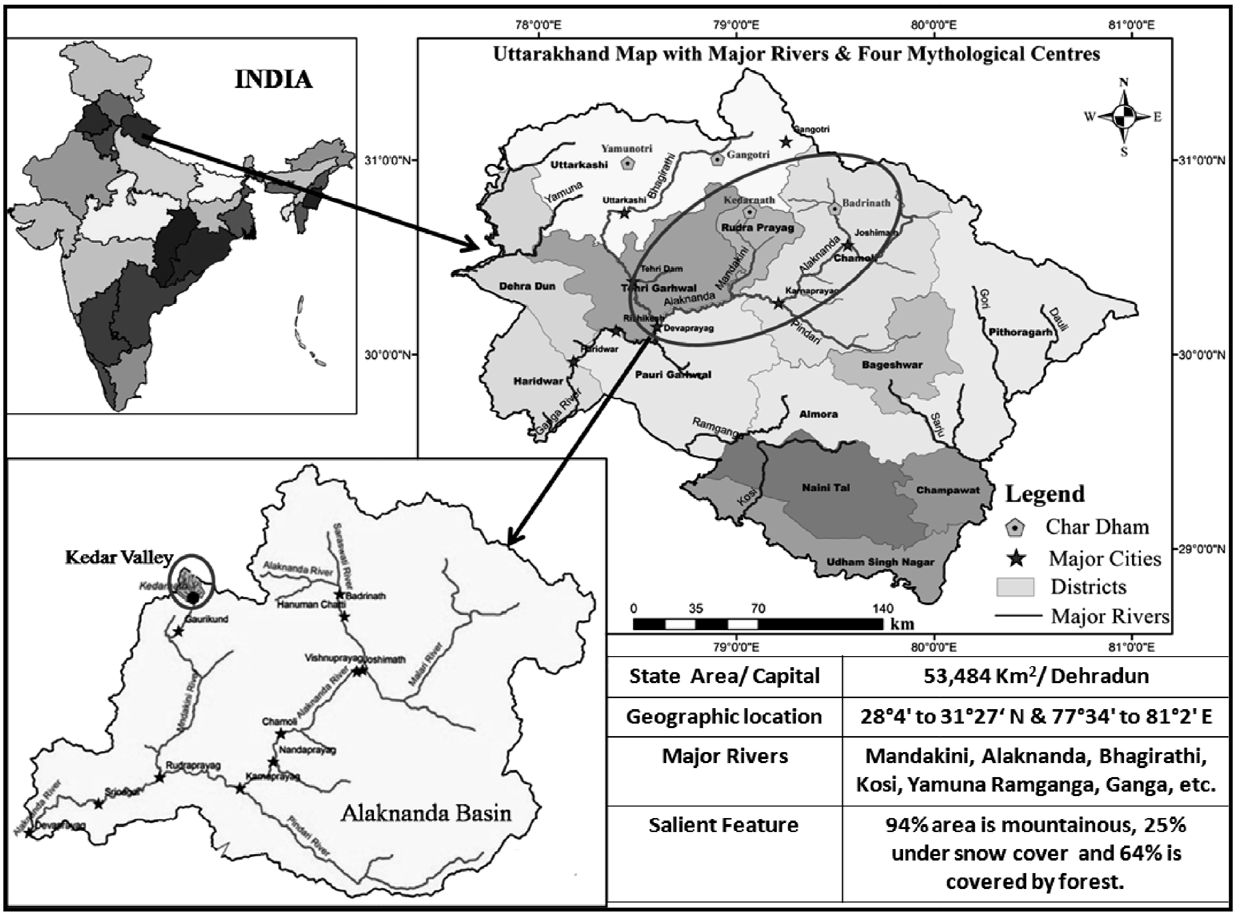

Fig. 1: Alaknanda river basin (along with Kedar valley) in Uttarakhand (India)

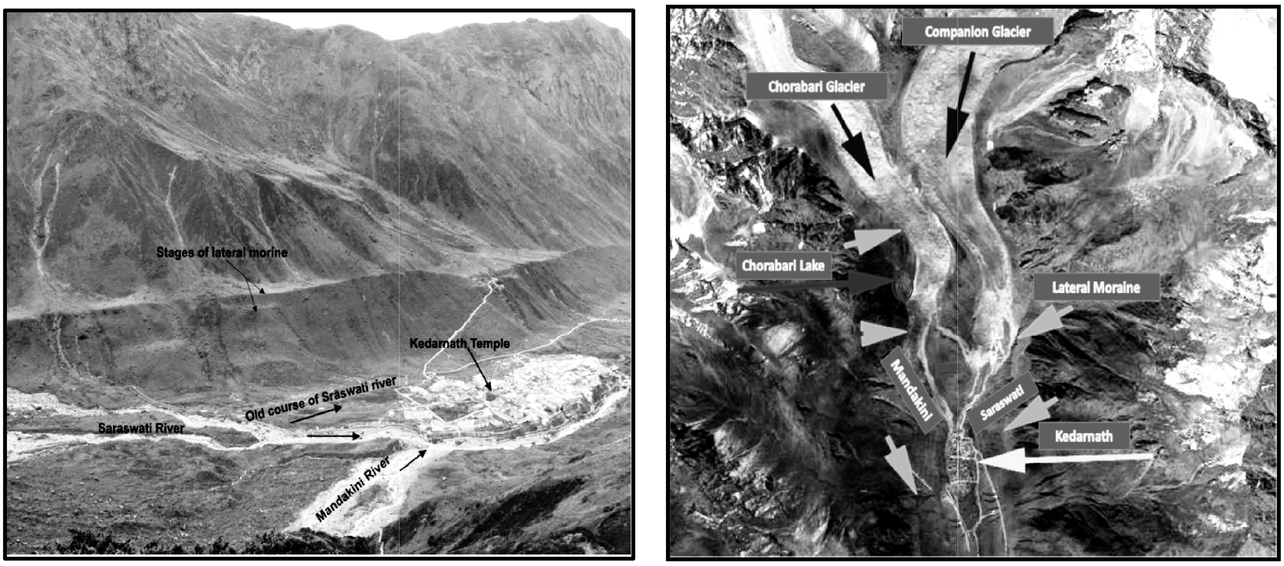

Fig. 2: (a) Geomorphological setup of the Kedarnath area (Source: Dobal et al., 2013) and (b) Landsat imagery indicating the position of Glaciers and Glacier Lake

located not too far away from the snouts of two mountain glaciers (Fig. 2b). The total catchment area of the Mandakini River up to Kedarnath is approximately 45 km^2, out of which 23% area is covered by glaciers (Dobhal et al, 2013). The catchment area, which presents diverse landscape, is in the glacier adapted U-shaped valley (Fig. 2a). The elevation varies from 3507 to 6915 m above mean sea level. Some well-known peaks in the area are: Bhart Khunta (6578 m), Kedarnath (6940 m), Mahalaya peak (5970 m) and Hanuman top (5320 m). Mandakini River originates from the Chorabari Glacier at an altitude of 3895 m, near Chorabari Lake and joins the Saraswati river which originates from the Companion glacier at Kedarnath (Fig. 2a & 2b), and passes through Rambara and Gaurikund. The Madhu Ganga and Dudh Ganga are the main tributaries that merge into the Mandakini river at Kedarnath town. Another equally important tributary of Mandakini River is Son Ganga which originates from Vasuki Lake (4040 m amsl) and has a confluence with the Mandakini River at Sonprayag (1709 m amsl). Mandakini finally merges with Alaknanda River at Rudraprayag (Fig. 1).

Topography and Landuse pattern

The landuse and topographic maps (Fig. 3a & 3b) indicate the diverse landscape and glacier adapted U-shaped Kedarnath valley. The presence of U shaped valley as well as moraines indicate the past existence of glaciers in this region. The Terra ASTER satellite DEM has been used to understand the topography of the basin. ASTER DEM obtained elevation data on a near-global scale to generate the most complete high resolution digital topographic database of Earth, at 30 meter spatial resolution. The elevation zones and the landuse of the study area is shown in Fig. 3. The elevation of the catchment

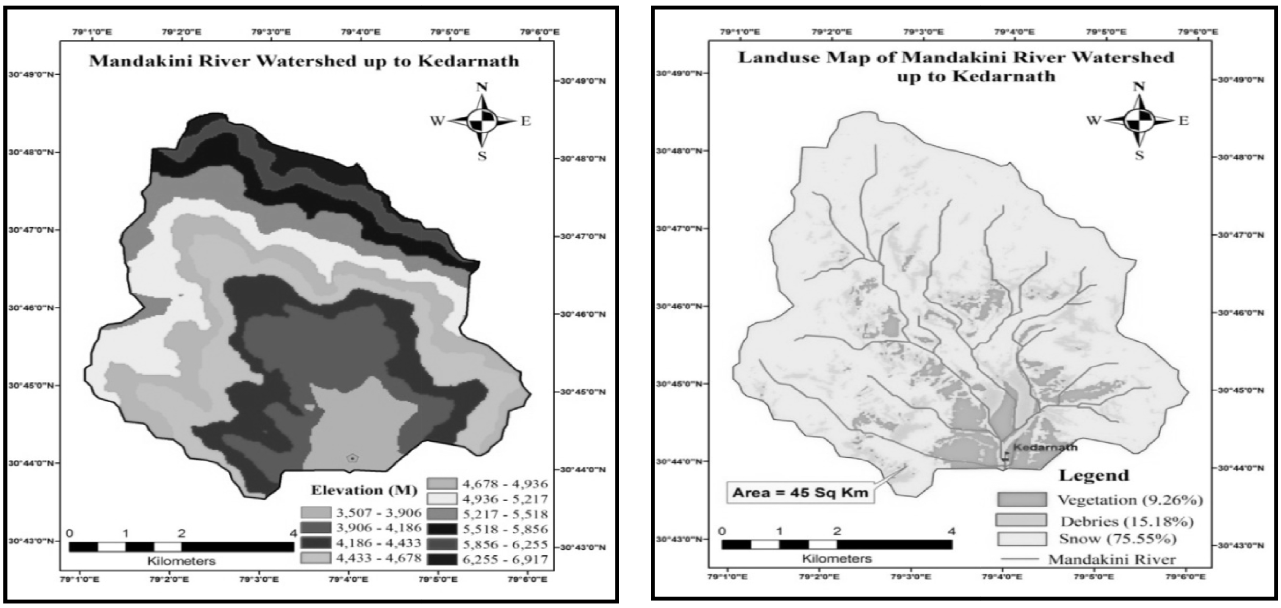

Fig. 3: Elevation zones and landuse map of the study area

area varies from 3507 to 6917 m above mean sea level. The leading landuse feature of the catchment is snow, which covers about 75% area of total catchment and responsible for the perennial nature of the drains. The high intensity of rainfall and serial cloudburst on this area boost the snow melt, which caused the flood hazards. The landuse map shows that there are number of streams approaching Kedarnath area. Further, there are multiple glaciers near the temple which makes the area extremely vulnerable. Such glaciers when move carry lot of debris on the way which results in high devastating hydraulic force of flow.

ROLE OF CLIMATE CHANGE IN OCCURRENCE OF FLOOD DISASTER

Early and Unusual Monsoon Behavior

The tragedy was triggered by the early occurrence of heavy unseasonal rains in north India. Such rains occurred two to three weeks in advance of what is normal for this region. The glaciers melted faster when water falls on ice, and the massive run-off began to engorge the river that caused heavier flow in extreme event happened in the month of June. According to National Institute of Hydrology Roorkee, the 370 millimeter rainfall in Dehradun happens to be the highest ever single day rainfall in June for the state (the previous highest being 350.5 millimeter in 1970). It may also be noted that heavy rainfall was not just confined to the Mandakini valley, but, it also covered a large region from the western Himalayas to the Central Himalayas. Such extreme and unseasonal rainfall indicate a global warming-induced climate change phenomenon. Warmer air due to global warming has the capacity to hold more moisture, leading to more intense bursts of rainfall. The natural monsoon cycle in India has already been badly disrupted, and a new cycle of extreme rainfall events and prolonged droughts has been reported from all over the country in the recent past. Normal district wise seasonal/ annual rainfall (mm) of Uttarakhand is shown in Table 1.

Heavy snow melt

The glacial regions above Kedarnath received fresh excessive snowfall when heavy rainfall hit the region. This rainwater, with higher temperature, falling on the snow might have led to heavy snow melt that resulted in heavy runoff wave with shooting velocity. The high momentum caused by this runoff along with heavy boulders struck the town with enormous ferocity. In general, the snowmelt has increased subsequent to the extreme rainfall and flood events.

Table 1: District wise Seasonal / Annual Rainfall of Uttarakhand in mm.

Name of District	Jan to March	April to June	July to Sept.	Oct. to Dec.	Annual Rainfall
Chamoli & Rudraprayag	241	222	883	28	1374
Pauri-Garhwal	36	52	973	114	1175
Dehradoon	111	209	729	26	1075
Haridwar	45	163	668	53	929
TehriGarhwal	53	143	724	20	940
Uttarkashi	169	190	320	31	910
Almora & Bageshwar	130	113	515	74	832
Nainital & Udham Singh Nagar	32	70	533	43	678
Pithoragarh & Champawat	101	110	385	14	610

the river. As reported by Indian Meteorological Department (IMD), there was 370 mm of rainfall in a single day at Dehradun, which is exceptionally rare. The average monthly rainfall in Dehradun for the month of June is 210 millimeter while in July and August it is about 600 millimeters. Though, the single day rainfall in excess of 400 millimeter has been recorded in the state during past, but none of these single day

Table 2: District wise rainfall during the disaster period (Source:http://sandrp.wordpress.com/2013/06/21/ uttarakhand-deluge-how-human-actionsand-neglect-converted-a-natural-phenomenon-into-a-massive-disaster/)

Period of Disaster (13.06.2013 to 19.06.2013)				
District (Name)	**Actual (mm)**	**Normal (mm)**	**% Dep**	**Cat.**
Almora	208.7	26.3	694%	E
Bageshwar	391.2	26.3	1387%	E
Chamoli	316.9	22.6	1302%	E
Champawat	351	33.5	948%	E
Dehradun	565.4	36.8	1436%	E
Garhwal pauri	149.7	15.8	847%	E

District (Name)	Actual (mm)	Normal (mm)	% Dep	Cat.
Garhwal tehri	327.7	22	1390%	E
Hardwar	298.8	21.6	1283%	E
Nainital	506.5	38.8	1205%	E
Pithoragarh	246.9	73	238%	E
Rudraprayag	366.3	53.9	580%	E
Udham singh nagar	157.7	40.2	292%	E
Uttarkashi	375.6	25.8	1356%	E

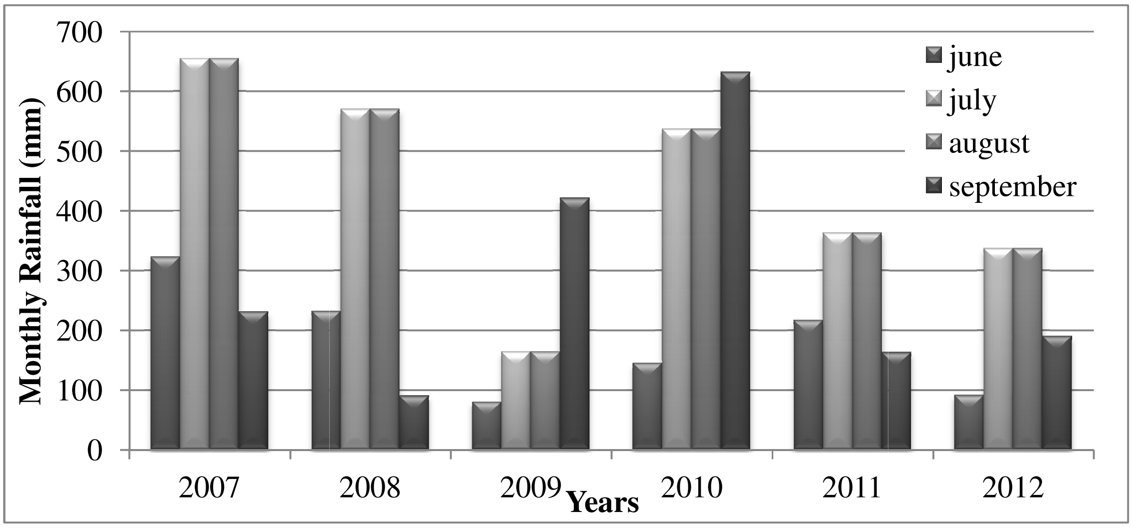

Fig. 4: Histogram of summer rainfall in the Kedarnath area (2007 to 2012).

Heavy Rainfall during this period

The heavy rainfall together with melting of snow in the surrounding Chorabari Lake washed off both the banks of the Mandakini river causing massive devastation to the Kedarnath town. The Wadia Institute of Himalayan Geology (WIHG) (http://www.wihg.res.in) meteorological observatory at Chorabari Glacier camp (3820 m amsl) recorded 210 mm rainfall in 12 hours between 15 June (5:00 p.m.) to 16 June (5:00 a.m.) 2013. On June 16, 2013 alone (from 5:00 a.m. to 5:00 p.m.), 115 mm rainfall was recorded, causing 325 mm rain in 24 hours. Another rain gauge station Kopardhar (30°31' 48", 78°44' 24"; 1836 m amsl) which is around 38 km from Kedarnath (aerial distance), recorded 58 mm on June 15, 121 mm on June 16 and 93 mm on June 17 with no rainfall on 18 June (Dobal et al, 2013). Table 2 shows the actual and historical normal rainfall during the third week of June 2013. It can be noticed from the % departure numbers that the rainfall at most of these locations was excessive. It can also be noted that heavy rainfall was not just confined to the Mandakini valley but the entire state as shown in Table 2 against the summer rainfall pattern of the Kedarnath as shown in Fig. 4.

Glacier and Glacier lake outburst flood (GLOF)

It is observed that another cause of this disaster was the glacier and glacial lake outburst flood (GLOF) of Chorabari

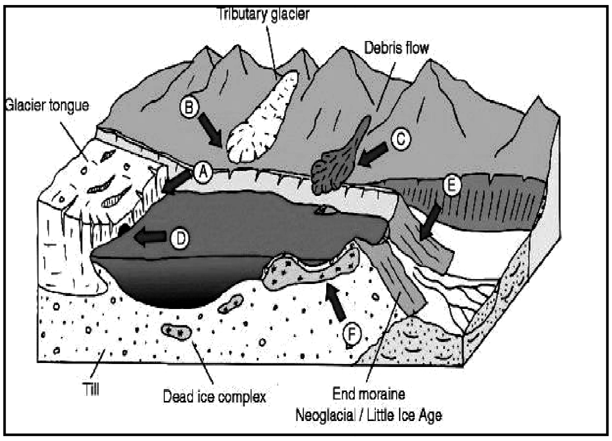

Fig. 5: (a) Chorabari lake before flood and (b) Mechanism of GLOF (Source: Iturrizaga, 2011)

Lake (Fig. 5a), located at the mouth of Chorabari glacier (Fig. 2b). Since the beginning of last century, number of glacier lake outburst floods (GLOF) has increased in the Himalayas. GLOFs are just one of the big threats from climate change in the Himalayas due to high emission of the GHGs. The risk of lake development is highest where the glaciers have low slope angle and low flow velocities or are stagnant. The formation of a glacier lake and its bursting mechanism is shown in Fig. 5 (b).

The potentially dangerous lake can be identified on the basis of the lake condition, dam, associated mother glaciers, and topographic features around the lake and the glacier.

ROLE OF ANTHROPOGENIC ACTIVITY IN OCCURRENCE OF FLOOD DISASTER

The flood disaster of 2013 has been officially termed as a natural calamity caused by serial cloudbursts and unprecedented heavy rainfall in the area. Some of the possible natural reasons are the heavy rainfall in the area alongwith the fragile nature of the Himalayan range, steep slopes, and poor soil stability. However, there are large number of anthropogenic activities which have added or worked as catalyst in worsening the its impact. These are discussed as follows:

Excessive Tourism

According to the Uttarakhand Tourism Development Board (UTDB) (http://uttarakhandtourism.gov.in), tourism in the state has increased by 168 percent over the past 12 years. The Char Dham Yatra, a trail that leads to four holy shrines of Hindu pilgrimage in the Himalayan state of Uttarakhand, opened to pilgrims on May 13, 2013. In a month, almost 1.3 million pilgrims completed the journey to the four shrines of Gangotri, Yamunotri, Kedarnath and Badrinath. While such intensive tourism brings in large revenue, the pressures of hosting such vast number of pilgrims are a burden on the region's natural environment.

The road is a major destabilizing factor for a mountain. It is an established fact that there is a straight correlation between increased tourism and higher incidence of landslides. Data with the Uttarakhand State Transport Department confirm that in 2005-06, 83,000-odd vehicles were registered in the state. The figure rose to nearly 1,80,000 in 2012-13. Out of these, cars, jeeps and taxis are the most preferred means of transport by tourists. This uncontrolled transportation and human interference with Himalaya is one of the key parameters of this disaster.

Around the Indian Himalayas new roads are constantly being built, old roads are being widened and maintained. Blasting away parts of the mountain are a part of the road-widening process. The whole process is surprisingly fast and pretty risky. Most of the construction companies, in order to clear the mountains for the development, are involved in blasting and heavy drilling of the rocks, spreading high-intensity vibrations. These are strong enough to disturb the area's tectonics and making the whole area susceptible to earthquakes of magnitude ranging from 7 to 8 and landslide. Fig. 6 shows the regular uncontrolled development on the bank of the river with heavy blasting in the state.

Construction of large number of hydropower projects

Uttarakhand has high potential for hydro power generation. As per one estimate, the state has a hydropower potential of about 20,000 MW which are being taken up by various central, state and private agencies. While constructing such projects, various anthropogenic activities take place and the flow regime of the river gets changed. Most of the river regime in the state has already been changed due to various stages of construction of various hydropower projects. This also aggravated the process of landslides and flash floods.

Sometimes, faulty operation of projects can also create greater disasters in the downstream areas. For example, during the Uttarakhand disaster, the operators of 400 MW Vishnuprayag hydropower scheme across the Alaknanda River did not open the gates when the river was flooded on June 16-17, 2013. This led to accumulation of massive quantities of boulders behind the dam. The river then bypassed the dam and created a new path. This created a sudden flash flood situation in the downstream area creating another disaster. It is reported that, this project suffered extensive damage during the floods.

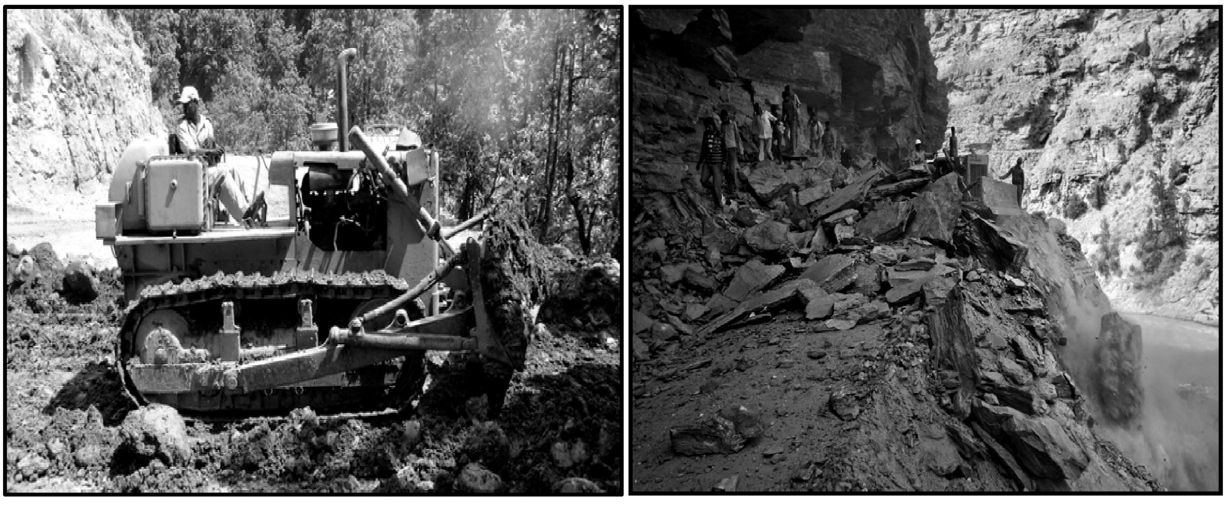

Fig. 6: Construction and blasting on the banks of Mandakini and Alaknanda rivers

(Source: http://www.downtoearth.org.in/content/uttarakhand-floods-disaster-human-induced)

Table 1: Basin wise operational hydro power plants in Uttarakhand

Basin	Large HPP (above 25 MW)		Small HPP (1-25 MW)		Mini-micro HPP (below 1 MW)		Total Hydro Projects	
	No. of projects	Capacity, MW	No. of projects	Capacity, MW	No. of projects	Capacity, MW	No. of projects	Capacity, MW
Alaknanda	1	400	10	54.75	21	2.22	32	456.97
Bhagirathi	4	1794	5	56.7	4	0.4	13	1851.1
Ganga sub basin	1	144	2	29.7	1	0.1	4	173.8
Ramganga	1	198	2	11.8	9	1.05	12	210.85
Sharda	3	415.6	4	7.7	21	4.45	28	427.75
Yamuna	5	474.75	1	3	3	0.445	9	478.195
TOTAL	**15**	**3426.35**	**24**	**163.65**	**59**	**8.665**	**98**	**3598.665**

(Source: Thakkar et al., 2013).

More than hundred power plants have already been constructed and are being in operation (Table 3).

Another issue of the hydropower projects is the disposal of muck. Each of the hydropower projects generates massive amount of muck. A large hydropower project could generate millions of cubic meters of muck. The projects are supposed to have planned for muck disposal with land acquired for muck disposal, transportation of muck to designated sites above the high flood level (HFL), creation of safety wall and stabilization processes. But the project developers find it easier to dump this muck into the rivers. During June 2013 floods in Uttarakhand, this illegally dumped muck created massive disaster in downstream areas.

Forest Encroachment

Almost all hydropower projects of Uttarakhand involve deforestation. Deforestation directly increases the concentration of GHGs, potential of erosion, landslides and floods since water now just runs off to the rivers. As per Forest Survey of India, 2011 (http://www.fsi.org.in/sfr_2011.htm), the forest area of the Uttarakhand in 2009 was about 64.79% (34,600 sq km out of 53,500 sq km). In 1970, it was about 84.9%, whereas, in year 2000, it was about 75.4%. A total forest area of about 5,400 ha was diverted for hydro power projects. Fig. 7 shows the variation of forest change during the years 1984 to 2013.

Landslides

More landslides occur due to unplanned development in the hills. Heavy machines plying on the *Kutcha* roads make the mountain weak and results in landslides more often. Road cutting aggravates the conditions of weak and unstable mountains. Outside contractors do not understand the local behavior of the mountains do not consider the experience of local people while tackling the issue of landslide. Construction induced landslides continues for years and the contractors and local people keep on indulging clearance of debris which otherwise aggravates the negative impacts of floods as it happened during 2013 flood disaster.

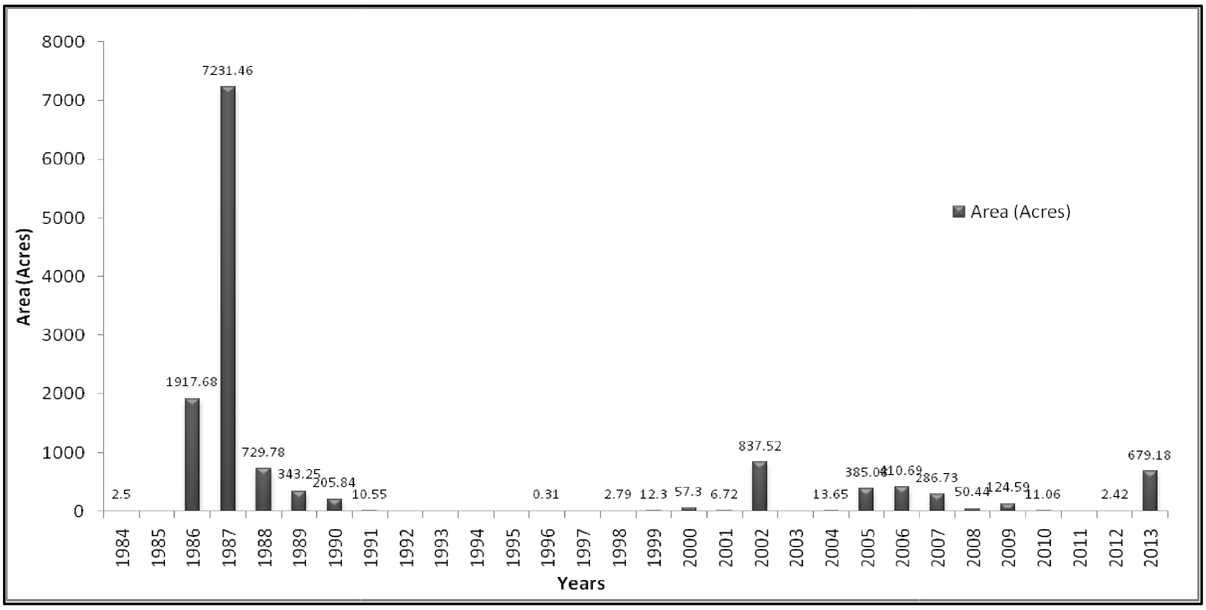

Fig. 7: Forest land diverted for Hydropower projects in Uttarakhand during 1984 to 2013.

ACCOUNT OF DAMAGE

The event has caused maximum damage at Kedarnath, which was it's epicenter. In Kedarnath area, due to increase in water level of *Vasu ki tal* (a glacial lake), a flash flood occurred that washed out several thousands of people in the downstream areas. The area was covered with 6 feet of sludge and cutoff from the remaining parts of the country. It is estimated that more than 10,000 people died and more than 1,00,000 peoples got affected. Most of them were pilgrims and tourists. More than 135 roads, about 150 bridges, more than 2,000 houses/buildings were completely or partially damaged (http://chimalaya.org/2013/06/19/). Still, there is no estimate of extent of damage to live stock. It is feared that a very large number livestock got washed away by this flash flood. Most of the people were stuck in the hills and died due to non-availability of food and water. The situation got worsened due to bad weather leading to severe cold conditions (leading to near zero degree Celsius temperature). Some of the worse hit towns were *Karanprayag* (Chamoli district), *Rudraprayag* and *Agastmuni* (Rudraprayag district) and *Srinagar* (Pauri

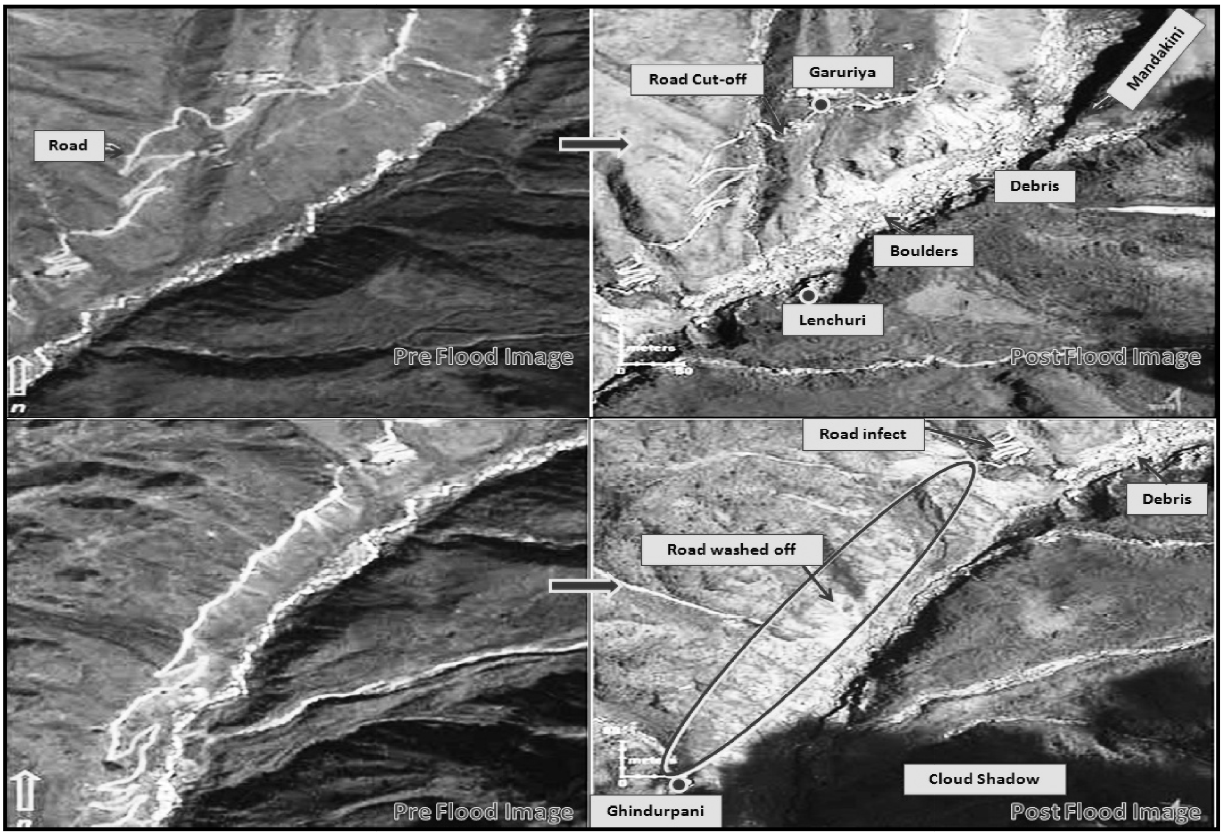

Fig. 8: Pre and post flood satellite Image of Cartosat 1 & 2A

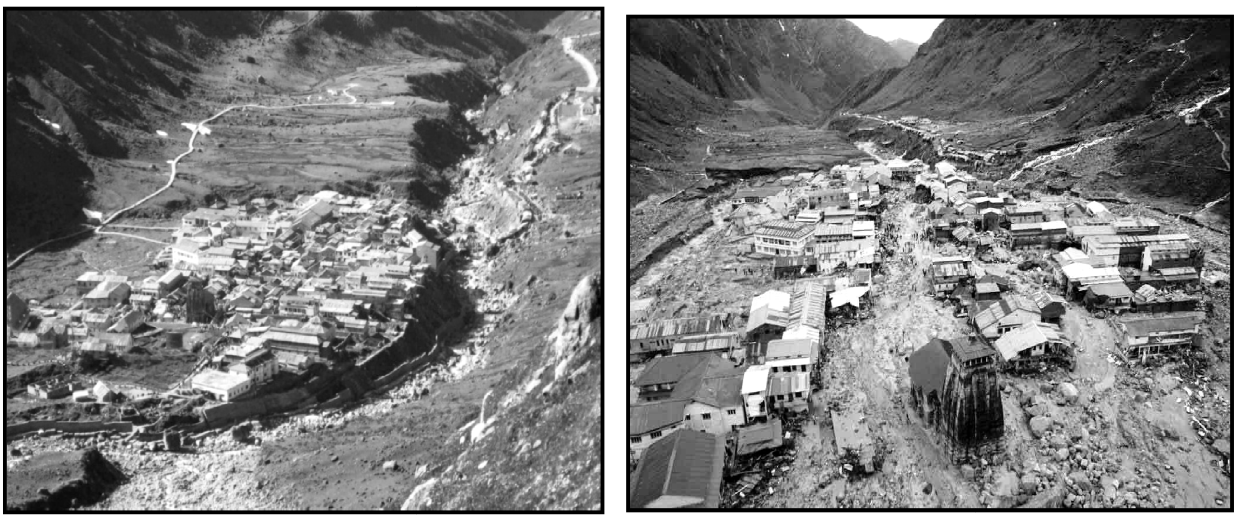

Fig. 9: Kedarnath town before and after calamity (Source: http://www.newsyaps.com)

Garhwal). The lowland and river bank areas of these towns got submerged in water. An incident of cloudburst occurred in *Fidogi* village in *Dhanolti* area (Tehri-Garhwal District) resulting in washing away of numerous houses and heavy loss of animals as people were not able to take away them. About 90 per cent of cash crops (particularly the apple crop) was completely damaged by the floods. Loss to the public and private property is estimated around US $ 2,000 million. Insurance companies are looking for claims worth more than US $ 1,000 million. The satellite images of Cartosat 1 and Cartosat 2A from National Remote Sensing Centre (http://www.nrsc.gov.in/) show the pre and post flood situation in the valley (Fig. 8). Fig. 9 shows the pre and post-event images of Kedarnath town around the temple. It may be noticed that the massive destruction was due to the large-scale debris carried away by the huge volume of water from upper reaches.

REMEDIAL MEASURES TO HANDLE SUCH THREAT IN FUTURE

Although flash floods are by their nature difficult to predict and control, it is possible to reduce the risk to lives and property through different measures. Some of the suggestions for reducing the impacts of such extreme events are as follows:

- Forecasting such hydrological events on the basis of scientific approach.
- Planned development of infrastructure with effective tourism planning can help in mitigating such events and thus reduce the impact.
- Inventory of glaciers and glacial lakes in the region can help in effective monitoring.
- One should use the techniques Doppler Radar System for flood warning and the remote sensing for the holistic data base of agriculture, water resources, forests, pastures, landscapes and other natural resources in the hilly terrain of the Himalayas.
- Short and long term structural measures should be adopted for restricting the quantity and the passage of the flood (Shrestha A. B., 2010). Table 4 describes some structural and non-structural measures that can be adopted to manage such floods. A combined and integrated approach should be adopted.
- Flash floods should be addressed through the integrated flood management approach and through the disaster risk management plans.
- There should be a better co-ordination among various state and national agencies for managing such events. Further, as the floods have local, specific, and sudden nature, local authorities and communities should be involved and educated in preparing plans for better management and to mitigate its adverse impacts.

CONCLUSION

The event of June 2013 have resulted in the massive destruction in Kedarnath valley. The destruction was caused due to shooting velocity along with large-scale boulder and debris movement. Another notable aspect of the event was the occurrence of highly intense rainfall before the usual onset of monsoon. It teaches us the lesson that heavy rainfall events are not confined to the monsoon season only but can occur during pre-monsoon season as well. Therefore, one has to be vigilant all the time. Further, another compounding factor was that the glacial regions above Kedarnath had received fresh and excess snowfall when heavy rainfall hit the region. It is highlighted that the damages triggered by cloudburst and GLOFs can be considerably reduced by an effective forecast and early warning system. Prior moraine dam lake outburst analysis could have predicted the extent of damage by such disaster. From geotechnical point of view, the slope stability analysis (considering deep failure of surface and seepage force) due to heavy rainfall may help in identifying the problematic areas. Rainfall monitoring stations must be installed in the high Himalayan areas. Excess rainfall/cloud burst was the main reason, but huge deforestation, high intensity blasting all over the hill, haphazard construction of houses (even in the river terrace region), checking of water at number of places along with mining have added to the

Table 2: Structural and non-structural measures for flash flood risk management

Structural	• Catchment interventions (agriculture and forestry actions) and water control work • River training works (check dam, Gabion structure and brushwood dam, etc.) • Flood control measures (passive control, water retention basins, river corridor enhancement, rehabilitation and restoration)		
Non-structural	Risk acceptance	Tolerance strategies	• Tolerance • Emergency response system • Insurance
	Risk reduction	Prevention strategies	• Delimitation of flood areas and securing flood plains • Implementation of flood area regulations • Application of financial measures
		Mitigation Strategies	• Discharge reduction through natural retention • Emergency action based on monitoring, warning, and response systems (MWRS) • Public information and education

(Source: Kansal et al. 2014)

devastation of this magnitude. Further, whole of this Himalayan belt falls under the active seismic belt and is therefore prone to such devastation. So, it can be concluded that this event is not a "natural" disaster, but, a synergic impact of nature and anthropogenic activities. The anthropogenic activities have resulted in the urbanization, greenhouse gas emission and the various climatic factors which in turn has impacted the extreme weather conditions.

REFERENCES

1. *Dobhal, D. P., Gupta, A. K., Mehta, M., Khandelwal, D. D., 2013. Kedarnath disaster: facts and plausible causes, Current Science, 105(2), 171-174.*
2. *Forest Survey of India (FSI), 2009. India State of Forest Report 2009, Dehradun (India), http://www.fsi.org.in/sfr_2011.htm*
3. *Indian Meteorological Department (IMD). http://www.imd.gov.in/Welcome%20To%20IMD/Welcome.php*
4. *IPCC -2007, Climate change 2007. The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge: Cambridge University Press.*
5. *Iturrizaga, L., 2011. Glacier lake outburst floods, In Encyclopedia of snow, ice and glaciers, pp. 381-399, Springer Netherlands.*
6. *Jain, Sanjay K., Lohani, A.K., Jain, Sarad K., 2013. Flash Flood! Threatening the Himalayan Region, Science Reporter (SR), Vol. 50, (8), 12-18.*
7. *Kansal, M. L., Shukla, S., Tyagi, A., 2014. Probable Role of Anthropogenic Activities in 2013 Flood Disaster in Uttarakhand, India, In World Environmental and Water Resources Congress 2014@ Water Without Borders, pp. 924-937, ASCE.*
8. *National Remote Sensing Centre (NRSC). http://www.nrsc.gov.in/*
9. *Shrestha, A. B., 2010. Managing Flash Flood Risk in the Himalayas, Information Sheet # 1/10, International Centre for Integrated Mountain Development (ICIMOD), Kathmandu.*
10. *Thakkar, H., Dandekar, P., Pujari, D., Saikia, P.J., Gaud, G., 2013. Dams, Rivers and People, South Asia Network on Dams, Rivers and People, Vol. 11, No. 5-6.*
11. *Uttarakhand Tourism Development Board (UTDB). http://uttarakhandtourism.gov.in*
12. *Wadia Institute of Himalayan Geology (WIHG). http://www.wihg.res.in/*
13. *http://chimalaya.org/2013/06/19/disaster-in-uttarakhand-india-huge-death-toll/*
14. *http://en.wikipedia.org/wiki/Kedarnath*
15. *http://sandrp.wordpress.com/2013/06/21/uttarakhand-deluge-how-human-actionsand-neglect-converted-a-natural-phenomenon-into-a-massive-disaster/*
16. *http://www.downtoearth.org.in/content/uttarakhand-floods-disaster-human-induced*
17. *http://www.newsyaps.com/disaster-in-uttarakhand-floods-kill-over-150-kedarnathtemple-stands-amid-ruins/29362.*