CLIMATE CHANGE, LAND USE AND LAND COVER CHANGE DETECTION AND ITS IMPACT ON HYDROLOGICAL HAZARDS AND SUSTAINABLE DEVELOPMENT: A CASE STUDY OF ALAKNANDA RIVER BASIN, UTTARAKHAND, INDIA

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Abstract: Climate change, land use and land cover change detection and its impact on hydrological hazards and sustainable development: a case study of Alaknanda river basin, Uttarakhand, India. Extreme climatic events impact on the natural ecosystems of Alaknanda river basin which affect the socio-economic condition of the rural communities, loss of life, livelihood and natural resources. They pose a serious threat to normal life as well as the process of sustainable development. Rivers are fragile ecosystems which are globally important as water tower of the earth, reservoirs of rich biodiversity, and a popular destination for recreation, tourism and culture heritage. Rivers provides direct life support base for humankind. The unique Geo-climatic condition of Garhwal Himalaya, Alaknanda River basin, Uttarakhand makes it one of the most vulnerable regions in the India. Hydrological hazards are sudden calamities, which involve loss of life, property and livelihood. This paper presents a methodological approach for the integration of extreme events, climatic vulnerability, land use scenario, and flood risk assessment. Anthropogenic activities are continuously disturbing the natural system of the Garhwal Himalaya and its impact on extreme hydrological events. Factors causing these changes have been attempted to be understood through the use of GIS and Geospatial techniques. Human interference, unscientific developmental activities, agriculture extension, tourism activity and road construction are creating the hydrological hazards. Soil erosion and landslide have been recognised as major hazards in the high altitude region of Himalaya. This paper has analysed and evaluates the climate and livelihood vulnerability assessment and its adaptation for sustainable development in the *near district headquarter* (NDH) & *away district headquarter* (ADH) determined mainly by a weighted matrix index. The Geospatial technique is used to find out the land use/cover change detection and secondary data is taken to carry out the analysis work. Primary data from each hotspot has been collected through a questionnaire survey and a Participatory Research Approach (PRA) procedure that is based on the LIFE approach. The LIFE Approach is based on **L**ivelihood options, **I**nstitutional participation in adaptation policy design and implementation, **F**ood security and **E**mpowerment parameters like health and education. This parameter is important in building resilience capacity and ensuring sustainable development

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pathways and provides the various mitigation processes from hydrological hazards. This paper has identified the vulnerability issues and suggest an adaptation method for sustainable development strategy and hydrological hazards mitigation planning for the development in the Alaknanda river basin, Uttarakhand, India.

Key-words: Extreme Climatic Events, Disaster Risk Reduction, Livelihood Vulnerability Index, Ecological Challenges, and Sustainable Development

1. INTRODUCTION

Climate change is increasingly recognised as a critical challenge to ecological health, human well-being, livelihood security and future development (Singh and Heitala, 2014). The risks of climate change and extreme events such as drought and flood have substantial impacts on the economy and natural systems. Agriculture, livestock, and water resources are among the most vulnerable systems. According to Roy and Singh (2002), climate changes and their associated extreme events will significantly alter productivity in agriculture and forest ecosystem, which in turn will affect the socio-economic conditions of many societies. Climate change is expected to increase the frequency and intensity of current hazards and the probability of extreme events, and also to spur the emergence of disaster (Nicholls and Lowe, 2006).

Extreme climatic events like rainfall, soil erosion, landslides, debris flows, cloud burst and flash floods owing to the failure of natural dams and glacial lakes outburst flood (GLOF) are the main types of natural and hydrological hazards within the Alaknanda river basin, Uttarakhand. In most cases, these natural disasters are triggered by extreme weather conditions (high or extreme rainfall events) during the monsoon period. The impact of utmost events on the extremely vulnerable Himalayan mountain ecosystem is increased by many folds owing to inherent geological character, geomorphology (topography), seismicity, land use pattern and other anthropogenic activities such as urbanisation, dam construction, haphazard constructions, deforestation etc (Pandey et.al, 2014).

Mountains are fragile ecosystems which are globally important as water tower of the Earth, reservoirs of rich biodiversity, a popular destination for recreation, tourism and culture heritage. Mountain provides direct life support base for humankind (Roy and Singh, 2002). The Himalaya is the vital life supporting systems of the Indian subcontinents. Extreme climatic events impact on the natural ecosystems of Alaknanda river basin which affects the socio-economic condition of the rural communities, loss of life, livelihood and natural resources. They pose a serious threat to normal life as well as the process of sustainable development. Thus, the human life is multi-dimensional and affecting it in all aspect such as domestic, social and economic condition etc.

Nature of the Problems. The Himalayas is a relatively young mountain range with a fragile geology prone to landslides, soil erosion and mass movement. The flash flood on 17 June 2013 destroyed towns, villages, roads and bridges for more than 60 miles along the banks of the Mandakini River (Tributaries of Alaknanda River). Occurring on the 16th to 17th June, 2013, the excessive rainfall accompanied by the Glacial Lake Outburst Flood (GLOF) of moraine-dammed Chorabari lake immediately above the township of Kedarnath led to a condition of sudden emptying of 400 meters long, 200 meters wide, and 15-20 meters deep glacial lake within a space of 5-10 minutes resulting in an unprecedented deluge of immense power. The force of this high gradient flash flood was huge as it destroyed the Mandakini banks between Kedarnath and Sonprayag engulfing the entire township of Kedarnath, Rambara and Gaurikund. The large number of hotels, restaurants, houses, bridges, roads and others form of building structure were razed to the ground. Many people died in the tragedy but more serious was the fact that the dead bodies were lost in the deluge (Plate 1). The local economy which thrived on providing services to pilgrim beside subsistence livelihood was completely grounded. About 4200 villages were affected in Uttarakhand, 11091 livestock were lost and 2513 houses were completely destroyed (Joshi, 2016).

Photo 1. Nearby Kedarnath temple, 2014. Source: Primary survey, 2014

The Himalayas have already been disturbed by a high degree of anthropogenic activity, change in land use/land cover change pattern and consequent geological hazards of which landslides, rock fall, soil erosion and tree falling are of worth mentioning. The major ecological degradation such as deforestation is accelerated due to hill road construction, mining activity, hydropower, landslides, and soil erosion which collectively create several environmental problems (Sinclair, 2003, Pandey et.al, 2014).

Study Area. The Alaknanda Basin extends between $30^0$00’ N to $31^0$00’ N and $78^0$45’ E to $80^0$00’ E, covering an area of about 11,396 Km^2. It represents the eastern part of the Garhwal Himalaya. Out of the total area of the basin 433 km^2 is under glacier landscape and 288 km^2 is under fluvial landscape. Uttarakhand state has eighteen development blocks of Bageshwar, Chamoli, Rudraprayag, Tehri and Pauri Garhwal and Pithoragarh Districts (Figure 1).

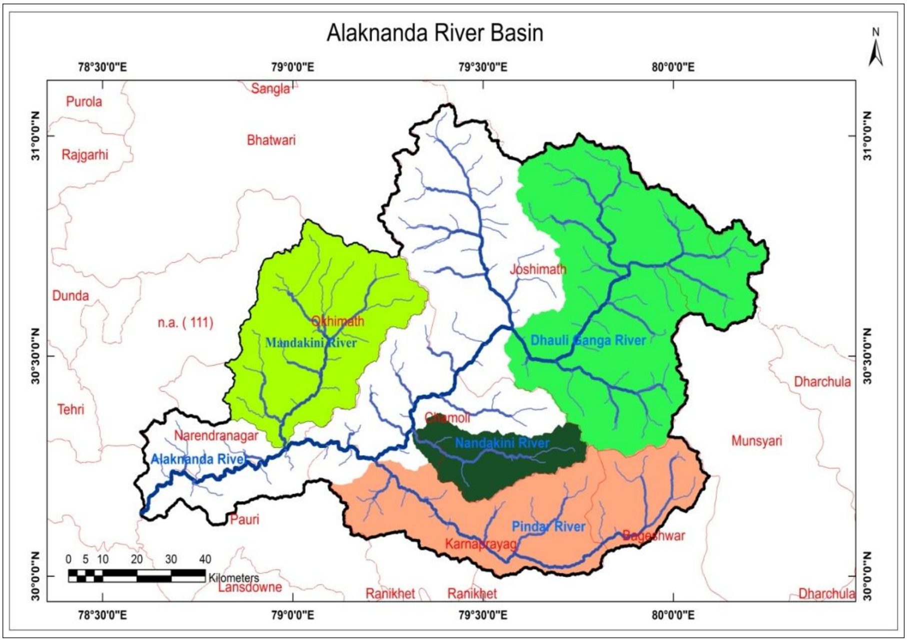

Figure1. Geographical Location of the Study Area, Alaknanda River Basin

The Alaknanda river Basin is characterised by hilly terrain, deep gorges and river valleys. The towns along the bank of Alaknanda River are Badrinath, Vishnuprayag, Joshimath, Chamoli, Nandaprayag, Karanprayag, Rudraprayag, Srinagar and Devprayag. An altitudinal variation from 442 m to 7,816 m in the Alaknanda catchment has given rise to a variety of climates ranging from sub-tropical, temperate, subalpine and to alpine.

2. RESEARCH METHODOLOGY AND DATA BASE

Both qualitative and quantitative methods have been used in the study. The study will be based on both primary and secondary data. Perception of local community regarding different aspects of sustainability, hazard occurrences and its management was recorded through reconnaissance survey and a semi-structured questionnaire. The Simple Random Sampling Technique was used for the primary survey. The satellite data LANDSAT TM image 1990, 2000 and 2015 has been used. The LANDSAT TM images taken from the Global Land Cover database were radiometrically and topographically corrected. Change matrices were identified from the attribute table. In this communication, the Likert scale was employed for analysing the peoples' perception regarding the origin, trend, frequency, magnitude and the techniques of control the hazards in Alaknanda River basin. In Likert scale categories have been assigned into 5 responses. Usually, the most negative responses are numerated into a given numerical values of 1, whilst the most positive response has a numerical value of 5 such as strong agree (5), agree (4), uncertain (3), disagree (2), strongly disagree (1) (Likert 1932). Villages were selected randomly under two category based on distance to district headquarter. 20 Villages and 200 households were selected for the primary survey. Villages such as Sarmola (Chamoli), Bank (Chamoli), Pipli (Pauri Garhwal), Pokhare (Pauri Garhwal), Sumari(Rudraprayag), Silli (Rudraprayag) , Nakot (Rudraprayag) , Ganganagar (Rudraprayag) , Baniyari (Rudraprayag) , Tari Gaow (Pithoragarh), and Ghansali (Rudraprayag) under the category of away from the district headquarter (ADH) and villages such as Naurakh (Chamoli), Gairi (Pithoragarh), Kota Kundil (Pauri Garhwal), Sakri Choti (Pithoragarh), Balmana (Pithoragarh), Pithoragarh (Pithoragarh), Sirtola (Pithoragarh), Kumaita (Pithoragarh) , Sari (Pithoragarh) and Pali Jaikhanda (Pithoragarh) are under near to district headquarter (NDH) has been selected for primary survey. From these villages, households were selected at random to collect the primary data with the interviews, through questionnaire and dependency on climate vulnerability, followed by informal and formal meetings and discussions with the other members.

2.1. Perceptions Regarding Causes of Hazards in Alaknanda River Basin, Uttarakhand

Deforestation, slope cutting, road construction and heavy rainfall were key driving factors causing several hazards particularly soil erosion, landslides and rock fall in the Alaknanda River basin (Table 1). It is triggered by both anthropogenic and natural causes. Slope cutting due to road construction, deforestation and lack of drainage technique were the basic factors identified for the origin of rock fall. Overgrazing, heavy rainfall and tourism activity were identified as other responsible factors for rock fall hazards and associated factors for soil erosion. About 72 respondents recognised the faulty agricultural practices as a tool for soil erosion hazard out of 100 respondents (Table 1). Deforestation and slope cutting are major causes for the natural hazards in Alaknanda river basin.

Table 1. Peoples' Perceptions Regarding Origin of Hazards (in Likert scale, 1-5)*

Hazards/ Causes	Lands-lides	Floods	Avalan-che	Cloud-burst	Fire	Rock-fall	Soil Erosion	Total
Deforestation	**5**	**5**	3	4	0	4	**5**	**26**
Slope cutting and construction of Roads	**5**	0	1	0	0	4	**5**	**15**
Improper Draining on slopes	3	1	0	0	0	2	**5**	11
Overgrazing	3	0	0	0	–	3	4	10
Steep Slopes	2	1	4	0	0	2	3	12
Heavy Snowfall	0	1	5	0	0	1	1	8
Glacial Lake Outburst	0	1	1	0	0	1	0	3
Heavy Rainfall	**5**	**5**	2	3	0	1	4	**20**
Changing Land Uses	2	1	1	2	0	1	2	9
Tourism	2	1	1	1	3	2	1	10
Faulty Agricultural Practices	1	1	1	1	1	0	2	7
Total	**28**	17	19	11	4	**21**	**32**	

***Source: Compilation by Author, 2016**

Cloudbursts, flash floods, forest fires, landslides, snow avalanches and mass movement are the main hazards. Out of 36 cloudburst events recorded during 1990 - 2014, fifteen (41.7 %) were reported. This indicates that the valley is more prone to cloudbursts.

The most landslides have occurred on human modified landscape and complex geodynamics phenomenon. It is directly related to local geo-environmental, slope cutting and excavation for the various development works. However, to stabilize this landslide site in order to restrict progressive failure both structural and non-structural approach is required. There should be strict regulation for felling of trees and afforestation should be encouraged. While local level policy makers are well aware of the issues related to the adverse impact of climatic change, their primary concern was about the immediate socioeconomic issues of local relevance.

2.2. Land Use/ Land Cover Change Detection in Alaknanda River Basin and Its Impact on Hydrological hazards

Soil loss is most prominent on the surfaces disturbed by the human activities such as deforestation, agriculture, constructional works, mining, quarrying, settlement etc. that land use pattern change during in three decades. The study analysed the land use/land cover changes and environmental vulnerability of the Alaknanda River Basin within the eastern Garhwal Himalaya, India. Satellite data has been analysed to dense forest area to be decreased from 28.65 per cent to 22.32 per cent and scrub forest area to be decreased from 38.08 per cent to 33.42 per cent during 1990 to 2015. The increase in the agricultural land area was observed all through, whereas open forest and riverbed areas decreased. Build up area has been increased from 4.66 per cent to 6.20 per cent area during 1990 to 2015. However, Build up area has been increased and forest area and water bodies area to be decreased, thus run off area of the natural drainage system to be decreased, then its effect on a landslide, soil erosion and extent and magnitude of a flash flood. Urbanisation is major issues in landslide and soil erosion. Within the table 1 shows that dense forest area to be decreased and urbanisation area to increase between 2000 and 2015, this is drastically changed in the land use cover pattern (Figure 2, 3 and Table 2).

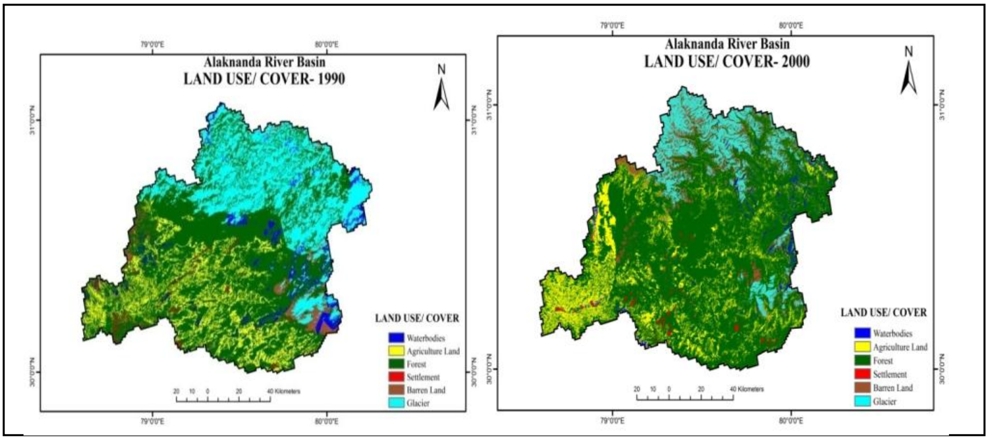

Figure 2. (a) Land Use/ Land Cover in 1990 and (b) Land Use/ Land Cover in 2000. Source: LANDSAT Satellite Images, 2016

In these vulnerable sites land use/cover changes correlated with high human interference such as increased agricultural encroachment, forest resources extraction and grazing. Our observation shows that the human activities have increased recently in higher elevations as a response to increased population pressure. Related policies could be the underlying driving forces of the changes.

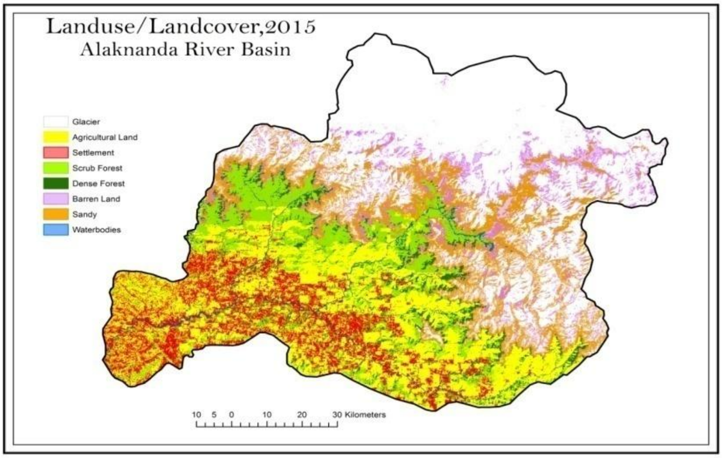

Figure 3. Land Use/ Land Cover in 2016. Source: LANDSAT Satellite Images, 2016

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Table: 2: Land Use/ Land Cover Classification of 1990, 2000 and 2015*

Land Use/ Land Cover Classification	1990		2000		**2015**	
	Sq. Km	%	**Sq. Km**	**%**	**Sq. Km**	**%**
Dense forest	3265.78	28.65	2933.31	25.73	2544.15	22.32
Scrub forest	4340.38	38.08	3949.71	34.65	3811.90	33.44
Water	123.40	1.08	118.26	1.03	119.10	1.04
Barren Land	1519.99	13.33	1745.68	15.31	1901.76	16.68
Agriculture	1016.55	8.92	1382.87	12.13	1599.57	14.03
Builtup	531.75	4.66	587.00	5.15	707.00	6.20
Glacier	598.22	5.24	679.23	5.96	712.59	6.25
Total	11396.10	100.00	**11396.10**	**100**	**11396.10**	**100.00**

*Source: LANDSAT Satellite Images, 2016

According to table 1 and table 2, shows that deforestation is major responsible causes for soil erosion, landslide and flash flood in Alaknanda river basin, Uttarakhand. That means land use/land cover changes are main responsible causes for extreme events.

2.3. Adopted vulnerability and adaptation assessment steps for Livelihood Vulnerability Assessment for sustainable development

Based on the literature (IPCC, 2007; and Younus, 2010) the following steps have been adopted to assess vulnerability and assessment in the NDH and ADH of along the Alaknanda river basin. The steps are:

1. Identification of the problem regarding vulnerability and assessment.
2. Define the objective within the environmental barrier/constraints (e.g. Extreme Climatic Event).
3. Quantify the vulnerability and assessment issues through weighted index scale.
4. Classify and rank the vulnerability and assessment issues.
5. Recommend a strengthening of the vulnerability and autonomous adaptation measures in the light of climate change.

These major components have been segregated as per the three dimensions of vulnerability (Pandey and Jha, 2012) such as

(1) Exposure- Natural Disaster (ND)
(2) Sensitivity – Health, Food and Water
(3) Adaptive Capability- Socio-Demographic Profile, Livelihood Strategies, Social Network and social capital.

$$\textbf{Exposure} = \frac{\textbf{We1ND}}{\textbf{We1}}$$

Where, We1 and We2 are the weight/no of components for the natural disaster and climatic vulnerability, it has been number of the indicator under the subcomponents.

$$\textbf{Sensitivity} = \frac{\textbf{Ws1H + Ws2F + Ws3Wa}}{\textbf{Ws1 +Ws2 + Ws3}}$$

Where, Ws1, Ws2, and Ws3 is the weight/ no of components for Major-components as Health, Food and Water respectively
The index for Adaptive Capability has been calculated as follow

$$\textbf{Adaptive Capability} = \frac{\textbf{Wa1SD + Wa2LS + Wa3SN+ Wa4SC}}{\textbf{Wa1 + Wa2 + Wa3}}$$

Where, Wa1, Wa2, Wa3, Wa4 is the weight/ no of components for the socio-demographic profile, livelihood strategies social network, and social network respectively. Major Components of NDH and ADH has been calculated by the

$$\textbf{Major Components (M)} = \frac{\sum \textbf{Total components}}{\textbf{N}}$$

M equals one of the major components (Socio-Demographic Profile, Social Network, Health, Food, Water, natural capital, Natural Disaster, represents the subcomponents, which makes up each major component, and *n* is the number of sub-components in each component. The percent of households reporting in their community was set at a minimum of 0 (High) and a maximum of 1 (Lowest) of a vulnerability index. Vulnerability index focuses on quantifying the strength of current livelihood including the dependence of natural resources and available infrastructures besides the prevailing local adaptive capability of communities. The vulnerability index has been acted as an instrument and developed with a view to providing an informed decision for the policy makers, and development organisations at the spatial scale (Table 3).

Table 3. Index Dimension of Vulnerability NDH and ADH Village's Household
Source: Compiled by Authors, Primary Survey

Vulnerability Components	Major Components	Vulnerability Components NDH	Vulnerability Components ADH
Adaptive Capacity	1.Socio-demographic Profile 2. Livelihood Strategies 3. Social Network 4. Natural Capital	**0.64**	**0.75**
Sensitivity	1. Health 2. Food 3. Water	**0.43**	**0.66**
Exposure	1. Natural Disaster, warning and impact	**0.29**	**0.44**

3. RESULTS AND DISCUSSIONS

The percent of households reporting in their community was set at a 0 (High vulnerability) and 1 (Lowest vulnerability). The result of data analysis for the major components and subcomponents comprising the livelihood vulnerability index developed for the NDH (Near the district headquarter) and ADH (Away District Headquarter) into eight sections such as socio-demographic profile, livelihood strategies, social network, natural capital, health, food, water, and natural disaster. The vulnerability of NDH and ADH village's households differs because of differences in the households' sensitivity, adaptive capacity and exposure to natural disaster, which further reflected in their disaster recovery strategies such as disaster risk reduction. The high response for the natural disaster by ADH village's community is due to poor infrastructure and facility, support from external resources besides high dependency on natural resources.

The study has highlighted the difference in the socio-demographic index of the NDH (0.46) and ADH (0.55). ADH village's households have more vulnerable than NDH village's households. The livelihood strategies of ADH village's households are less diversified than NDH village. The NDH households had more opportunity for adjustment within the framing system due to their traditional/local knowledge about the climate change responses and Government policy facilities. This is very important for disaster risk reduction. The NDH village's households had better accessibility in terms of facilities and livelihood options than ADH household, thus, opted for crop variety change and the introduction of new crops.

The social network status was similar (NDH-0.80 and ADH- 0.79) in both the regions. This shows that ADH and NDH village's households were interdependent and seeks co-operation among them. A large number of households reported having a strong social network in ADH villages. Families in ADH village reported less difficulty in acquiring adequate food and seed because of sufficient food grain production and social network within the village community.

In NDH village's households has reported the good health facility as a result of better livelihood options, government and private health facilities. ADH village's large numbers of households do not go for treatment in government and private hospitals and not have access to proper facilities for child delivery and immunization. In such households, even toilet facilities were unavailable in their houses. The highest number of households to report death or injury was reported in ADH villages. The high level of stress due to climate was noted in ADH (0.96), probably due to their high dependency on natural resources. The households of NDH village (0.68) reported the occurrence of more new diseases than the ADH (0.45), probably due to better communication and awareness about health hazards and health facility.

This paper has identifies the NDH and ADH village's households vulnerability level, which may be helpful in formulating the policy for sustainable development. To reduce the sensitivity of the households in the village, this, in turn, may help them to be more efficient in overcoming the shock caused by the disaster and re-establishing their livelihood. Vulnerability understanding and knowledge have been adaptation strategies for resilience help them in implementing non-structural mitigation measures, which also benefits overall development through capacity building.

3.1. Adaptation Techniques and HRD Skill for the Disaster risk Reduction

1. Communication skills, particularly in the event of the disaster crisis to communicate to all the parties concerned, Government, Voluntary agencies and local bodies etc.
2. Co-coordinating and networking skills.
3. Team building skills.
4. Motivating skills to improve and infuse self-confidence in the affected victims to take up the construction work required.
5. Interpersonal relationship skills to build the common cause and tackle the problems collectively in the affected villages.
6. Counselling to disaster affected victims and their families
7. Leadership skills to train the youth and community leaders in taking initiative, objective analysis of the crisis and launching an action drive for withstanding the crisis and tackling the crisis

The above-mentioned skills are essentially required and immensely useful for tackling disasters at different stages: (1) Preparedness stage (2) Mitigation stage (3) Rehabilitation stage through the post-disaster rehabilitation measures (Dhingra, 2012, Singh, 1992; Gardner, 1992).

The ministry of Environmental and Forest has prepared a National Master Plan for Disaster risk reduction. It is proposed to introduce a well-coordinated and integrated management such as:

1. Detection of a forest fire, through a good coordination network, efficient ground patrolling, communication network etc. Remote Sensing is also to be given due to importance in the fire detection and management.
2. Slope covered with grass
3. Forecasting and operation of early warning systems.
4. Disaster management through Panchayati Raj (PR).
5. Panchayati Raj (PR) may be very effective in using local tradition and wisdom supported with scientific applications

4. CONCLUSION

Alaknanda river basin is a disaster prone area in Uttarakhand, India. They must need the lessons emerging from the 2013 Uttarakhand tragedy especially in the context of the repeated indications of extreme climatic events. Ecologically sustainable development is the basic prerequisite for disaster mitigation. Equitable development will reduce the vulnerable issues and disaster. Governments must realise that they alone cannot take adequate measures. Communities and civil society organisations must be active partners. Glacial Lake Outburst Flood (GLOF), cloudbursts, landslides, flash floods, etc., are the natural hazards/disasters, which may not be stopped. But, the intensity of damage due to the occurrence of these phenomena can be reduced after adopting several measures. Public awareness program for people on causes and effects of landslides, climactic conditions that lead to landslides would be an extremely effective measure to prevent damages and Promotion of the education of disaster reduction, professional training on disaster prevention and establishment for a safe community and International collaboration and technologies should be encouraged.

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