Geotechnical Measures for Uttarakhand Flash Flood-2013, India

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ABSTRACT: Many "Run of the River" projects in the North West part of Himalaya have been frequented by "Cloud Burst" induced flash flood in since 2009, which is primarily attributed to climate variability and land use pattern changes due to unregulated developmental perspectives against the rising demand of tourist related establishments. Given the ageing population of vulnerable constructions along the hilly terrains, safety issues require more attention in the form of technical auditing cum inspections, routine monitoring, emergency drills, surveillance systems, and regularly updated emergency action plans. Added to this accelerated events of "cloud burst" induced flash flood in the hilly region has opened up Dam safety issues, which are rather debated in the court of law for which geo-professional intervention are to be looked into. This paper explains the climatic and other geo-morphological changes that might have caused Uttarakhand Flash Flood-2013. Damages to the geotechnical structures in the form of excessive erosion, landslides, siltation of catchment area of several Dams in Uttarakhand state of India are described along with some illustration of landslides mitigation by simple bio-engineering solution as one the means of reconstruction measures across the state.

KEYWORDS: Climate change, Landslides, Cloud burst, Retaining walls, Bio-engineering, Vetiver grass, Soil nailing, Geocell

1. INTRODUCTION

The 2400 km long Himalayan arc in the northern territory of India is the home of vigorous seismo-tectonic activities and also subjected to weather imbued hydro-geological-hazards that cause avalanches, landslides and flash floods. Landslides and slope instability problems are now being noticed in numerous Himalayan towns. Natural drainage often gets blocked or obstructed by human activity and surrounding hillsides get denuded because of increased human pressure. According to the Intergovernmental Panel on Climate Change scenarios, it is very likely that heavy precipitation will become more frequent and it's likely that future events will become more intense and localised. The Uttarakhand state in India is one of the 11 states facing mostly rainfall induced landslides and also affected with earthquakes (Figure 1). The problems are mounting up not merely due to the steep slopes, but because of the poor stabilisation of the slopes and absence of geotechnical and geological measures in the road constructions. Moreover, growing dimensions of human settlement and the climatic variability as notably found in the last one decade or so, have been causing extensive flash flood induced damages and loss to the establishment along the river terrains. As on date cloud bursts, flash floods, landslides added with many ongoing hydropower projects in this state, each project entailing dam, tunnels that need to be blasted through, the roads, townships and deforestation, the distress and damage potential goes up multi fold, particularly when there are no credible environment of social impact assessments at project or basin level (SANDRP). Systematic studies on the carrying capacity of reservoir dam and undefined means and methodologies towards credible compliance mechanisms to ICOLD standards are some of the important issues to be discussed in the paper.

According to ICOLD, there have been about 200 notable reservoir failures in 20th century in the world so far. Realizing the importance of dam safety, many countries in the world have initiated action to review the safety of dams in their countries. The review conducted by US Army Crops of Engineers has revealed that out of 8819 review inspection completed, 2925 dams were evaluated as unsafe. Of the various causes, inadequate spillway capacity was the primary deficiency found in 81% of the unsafe dams. The height of new dams and the volume of new reservoirs are increasing, while older dams are approaching an age at which material deterioration and decreasing operational reliability may dictate some repair and upgrading. Certainly, both the growing dimensions of new dams and the aging of older dams suggest a somewhat more rigid approach to safety aspects. Given the ageing population of dams, safety issues require more attention in the form of inspections, routine monitoring, evaluations, surveillance systems, and regularly updated emergency action plans. It is also important to update dams to contemporary standards, especially regarding spillway capacity and resistance to earthquakes.

Figure 1 Flash flood induced damages in Uttarakhand where massive reconstruction work is under way

Among all disasters riverine flooding is the most common of all environmental hazards and it regularly claims over 20,000 lives per year and adversely affects around 75 million people worldwide (Smith et al., 1996). The reason lies in the widespread geographical and geomorphological distribution of the tracks of rivers and floodplains and low-lying coasts, together with their longstanding attractions for human settlement (Ologunorisa and Abawua, 2005). Death and destruction due to flooding continue to be too common phenomena throughout the world today, affecting millions of people annually. Floods cause about one third of all deaths, one third of all injuries and one third of all damage from natural disasters (Askew,1999). India has to face loss of life and damage to property due to severe floods during the monsoons of 1955, 1971, 1973, 1977, 1978, 1980, 1984, 1988, 1989, 1998, 2001, 2004, and there after urban floods in major cities of India are taking place almost every year.

National Mission of Sustainable Himalayas, one of the nine missions under National Action Plan on Climate Change, had made a recommendation for protection of areas around the four pilgrimage sites of Gangotri, Yamunotri, Kedarnath and Badrinath (Figure 1) by creation of spiritual and ecological buffer zones around pilgrim places in the ecologically-sensitive region. The mission noted that construction of roads should be prohibited beyond at least 10 kms from protected pilgrim sites. In order to reduce the damage impact, national parks and sanctuaries, can be maintained as special areas, where there would be minimal human interference. It is therefore highly important to strictly regulate developmental initiatives in close vicinity of streams and rivers. Appropriate legislative interventions would be required for formulating a policy in this regard and firm executive action in accordance with letter and spirit of this policy would be required to ensure compliance of the same.

2. CLOUD BURSTS INDUCED FLASH FLOODS

A cloudburst is an extreme weather event often associated with climate variability across the globe, sometimes with hailstorm and thunder, which normally lasts no longer than a few hours but is capable of creating flood conditions. Colloquially, the term cloudburst may be used to describe any sudden heavy, brief, and usually unforecastable rainfall over a very specific area or typically in the mountainous areas in India. Meteorologists say the precipitation rate equal to or greater than 100 mm per hour is a cloudburst. These events are often reported when there is a shift of hot air from the ground up towards clouds which carry a large amount of rain drops. The temperature difference eventually causes the break, leading to the sudden discharge of water. The associated convective cloud can extend up to a height of 15 km above the ground. During a cloudburst, more than 20 mm of rain may fall in a few minutes. In such high amount of intense rainfall in the hilly areas of Uttarakhand state of India in June 2013, the country faced severe shock and devastation due to flash flood.

There are a number of global instances of cloudburst. In 1906 Guinea (Virginia in USA) received 234,95 mm of rainfall for 40 min, in 1916 Plumb Point (Jamaica) experienced 198,12 mm of rainfall for 15 min, Foc-Foc (La Reunion) in 1966 mm of rainfall for 13 hours, Ganges Delta (India) experienced 2,329 mm of rainfall for 20 hours in 1966, in 2010 Leh-Ladakh (India) received 250 mm of rainfall for 1 hour and in 2010 Pashan (Pune, India) received 182 mm for 1.5 hours. Figure 2 shows the cloudburst in Himachal Pradesh lying in the West side of Uttarakhand state in August 2015, killing 4 people. On July 1, 2016, 30 people are killed and 15 missing due to cloudburst in the Pithoragarh and Chamoli districts of Uttarakhand that measured 100mm of rain fall in 2 hrs.

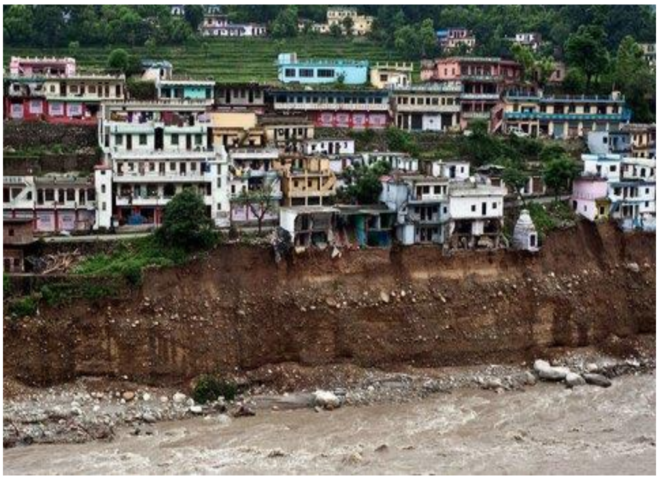
Figure 2 Flooded Dharampur market and bus station after a cloudburst in Mandi district, Himachal Pradesh in August 2015 (Photo: The Indian Express)

There are numerous examples in the past when flash floods in the Himalaya have been responsible for causing land slip and washed away village, bridge, roads disrupt communication for days (Dhar et al., 1975). In September 1880, due to intense fall of rain in the Garhwal-Kumaon hills, landslips and flash floods destroyed numerous villages. Same kind of incident reported in Darjeeling and Jalpaiguri district in June 1950. In July 1963, a portion of Pahelgam town and Kashmir washed away by sudden swift rising of nearby river. A major incident also took place in July 1970 in Alkananda valley in the Garhwal Himalaya. In recent past Uttarkashi, a district of Uttarakhand suddenly waterlogged due to flash flood caused by cloudburst. The district also faced the heavy flood in 1978, 1997 and 1998, mass landslide in Varunawat hill in 2003, 2007 and 2007, in Bhatwari village in 2011 (Onagh et al., 2012).

Flash floods are characterized by sudden rise and recession of flow of small volume and high discharge, which causes damages because of suddenness. It generally takes place in hilly region where the bed slope is very steep (Pal et.al, 2014). Flash flooding occurs when precipitation falls too quickly on saturated soil or dry soil that has poor absorption ability. The runoff collects in low-lying areas and rapidly flows downhill. Flash floods most often occur in normally dry areas that have recently received precipitation, but may be seen anywhere downstream from the source of the precipitation, even many miles from the source. Among all other factors cloudburst is one of the causes of flash floods in hilly areas. Flash floods have high velocities and tremendous erosive forces, and only extremely solid structures can withstand their destructive force. Rivers flowing beyond its capacity could turn into a deluge if there is a cloudburst. Such occurrences can also result in massive erosion of land, leading to landslides and destruction of roads and national highways.

The damage potential of flash floods is confined to the direct neighbourhood of the river (Figure 3), where the total damage usually is not very extensive in spite of the high flow velocity. The individual damage to structures or persons in such floods is very high. In recent times, flash floods have caused large losses of life only of people unfamiliar with the potential hazard, such as tourists, who camp in the mountain canyons. In some areas, flash floods can be avoided to some extent by flood control reservoirs (Plate, 2002).

(a)



(b)

Figure 3 Human settlements affected by flash flood in state of Uttarakhand in June 2013, (a) Destruction of tourism infrastructure built over river bed (b) Buildings in steep hill slope in danger due to flash flood induced river bank erosion

3. UTTARAKHAND FLASH FLOOD-2013

The flash flood event of Uttarakhand (2013), which is the worst disaster India faced after Indian Ocean Tsunami (2004) that killed more than 5000 people is attributed to some of the following factors, such as the uncontrolled tourism, illegal construction, unplanned and ill planned construction around several pilgrimage sites, widening of road without considering the geology and geomorphology, race of hydel projects, blasting during roads and dam project, large number of vehicular traffic infested with tourism. Absence of robust early warning system makes the situation worse for the disaster response managers of the state.

The Kedarnath shrine area (located at 3584 m above msl) (Figure 4a) faced two flash flood events, one starting around 8.15 pm on June 16 and second at 6.55 am on June 17. The flood originated from catchment that includes two mountain peaks: Kedarnath and Kedarnath Dome (6831 m elevation). Following torrential rains huge boulders broke away from Kedar Dome and ruptured the downstream Chorabari glacier (Figure 4e) and lake reservoir (Figure 4d), about 6 km upstream from the Kedarnath temple (Figure 4b) along the Mandakini river (Figure 4c). This description seems to suggest that this was also an event of GLOF (Glacial Lake Outburst Flood) (www.sandrp.in). Figures 5a and 5b show the Indian Space Research Organisation (ISRO) generated "Bhuvan" image, describing the location of Kedarnath temple and it's vulnerable location, where Glacial Lake Outburst Flood (GLOF) have taken place in addition to heavy rain fall in June-14-17, 2013.

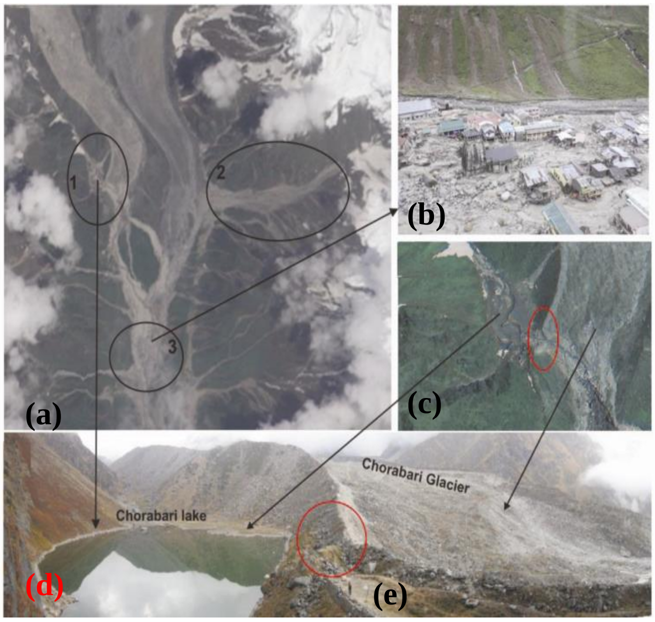
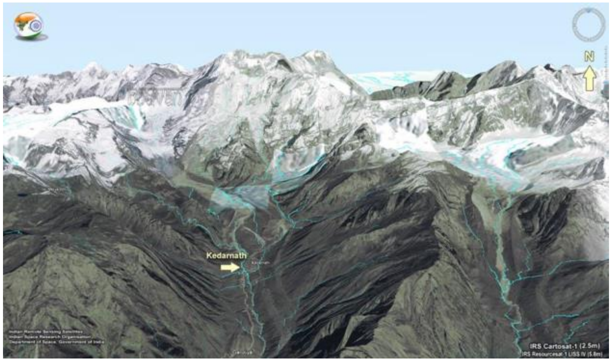
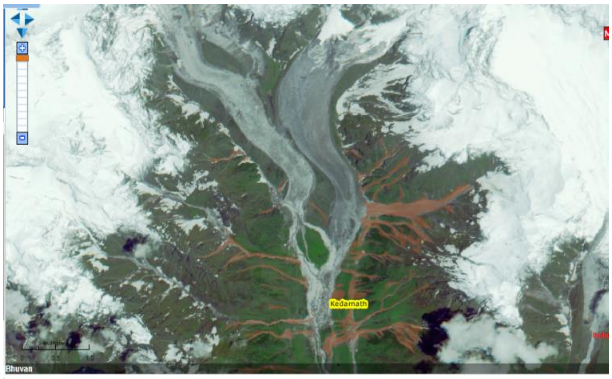


Figure 4 Areal view of Kedarnath flash flood (2013) along with the Chorabari Lake that was reported to burst out on 17th June 2013, causing severe impact the Shrine complex

This event caused widespread damages and losses that have contributed to decline in economy, tourism of Uttarakhand state of India but it offers opportunities for advancement and growth. If planned effectively, the recovery and reconstruction program could offer opportunities to rebuild better, take advantage of economically productive options. Reconstruction in Uttarakhand is to be taken up as an opportunity to reduce the vulnerability of the state against impending natural and manmade disasters by relocating settlements in safer sites, introducing new building technologies for hilly terrains, up-dating national building codes for disaster safe hill areas, and by enhancing (through multiple strategies) disaster preparedness at different levels. The reconstruction process shall enable effective recovery support to flash flood impacted areas of Uttarakhand in a unified and collaborative manner. It also focuses on how best to restore, redevelop and revitalize the health, social, economic, natural and environmental fabric of the community and build a more resilient state.



(a)



(b)

Figure 5 Geo-spatial view of Flash flood area and its vulnerable surroundings before the flash flood of June 17, 2013 (ISRO, "Bhuvan" image)

Unprecedented destruction by the rainfall witnessed in Uttarakhand state (Figure 6) was also attributed, by environmentalists, to unscientific developmental activities undertaken in recent decades contributing to high level of loss of property and lives (Kala, 2014). Roads constructed in haphazard style, new resorts and hotels built on fragile river banks and more than 70 hydroelectric projects in the watersheds of the state led to a "disaster waiting to happen" as termed by certain environmentalists (Shadbolt, 2013). The environmental experts reported that the tunnels built and blasts undertaken for the 70 hydro electric projects contributed to the ecological imbalance in the state, with flows of river water restricted and the streamside development activity contributing to a higher number of landslides and more flooding.

Figure 6 Rescue scenario of flash affected people by Indian Army and National Disaster Response Force deployed from June 18-27, 2013

4. DAMAGED HYDRO-ELECTRIC PROJECTS

A large number of hydropower projects (Figure 7) are coming up in the state of Uttarakhand and some of them have suffered damage due to the heavy rainfall induced flash flood in Uttarakhand and nearby state of Himachal Pradesh. Some of the projects that have suffered but unassessed damage include (SANDRP):

a. 520 MW under construction Tapovan Vishnugad Hydro Electric Project (HEP) has suffered damaged by rains on June 16, 2013: While construction of diversion tunnel was completed in April 2013, the same was washed away due to heavy rains on June 16. It also caused serious damages in the coffer dam of the project.
b. 400 MW Vishnuprayag HEP of JP Associates has suffered serious, but as yet unassessed damage. As per MATU PR (http://matuganga.blogspot.in/), the project has also been cause of damage in Lambagad village,
c. 76 MW Phata Byung HEP of Lanco in Mandakini Valley in Uttarakhand
d. 99 MW Singoli Bhatwari HEP of L&T in Mandakini Valley in Uttarakhand and it was reported that the water level of the river has gone up due to the silt dumped by dams.
e. Kali Ganga I, Kali Ganga II and Madhyamaheshwar HEP, all in Mandakini Valley hit by mudslides
f. Assiganga I-IV projects on Assiganga river in Bhagirathi basin in Uttarakhand
g. 65 MW Kashang HEP in Sutlej basin in Himachal Pradesh
h. 280MW Dhaulganga Project of NHPC in Pithoragarh district of Uttarakhand and it was reported the power house and township were submerged,
i. The 330 MW Srinagar project, a cause for downstream destruction, has itself suffered massive damages on June 17, 2013, with breach of its protective embankment.

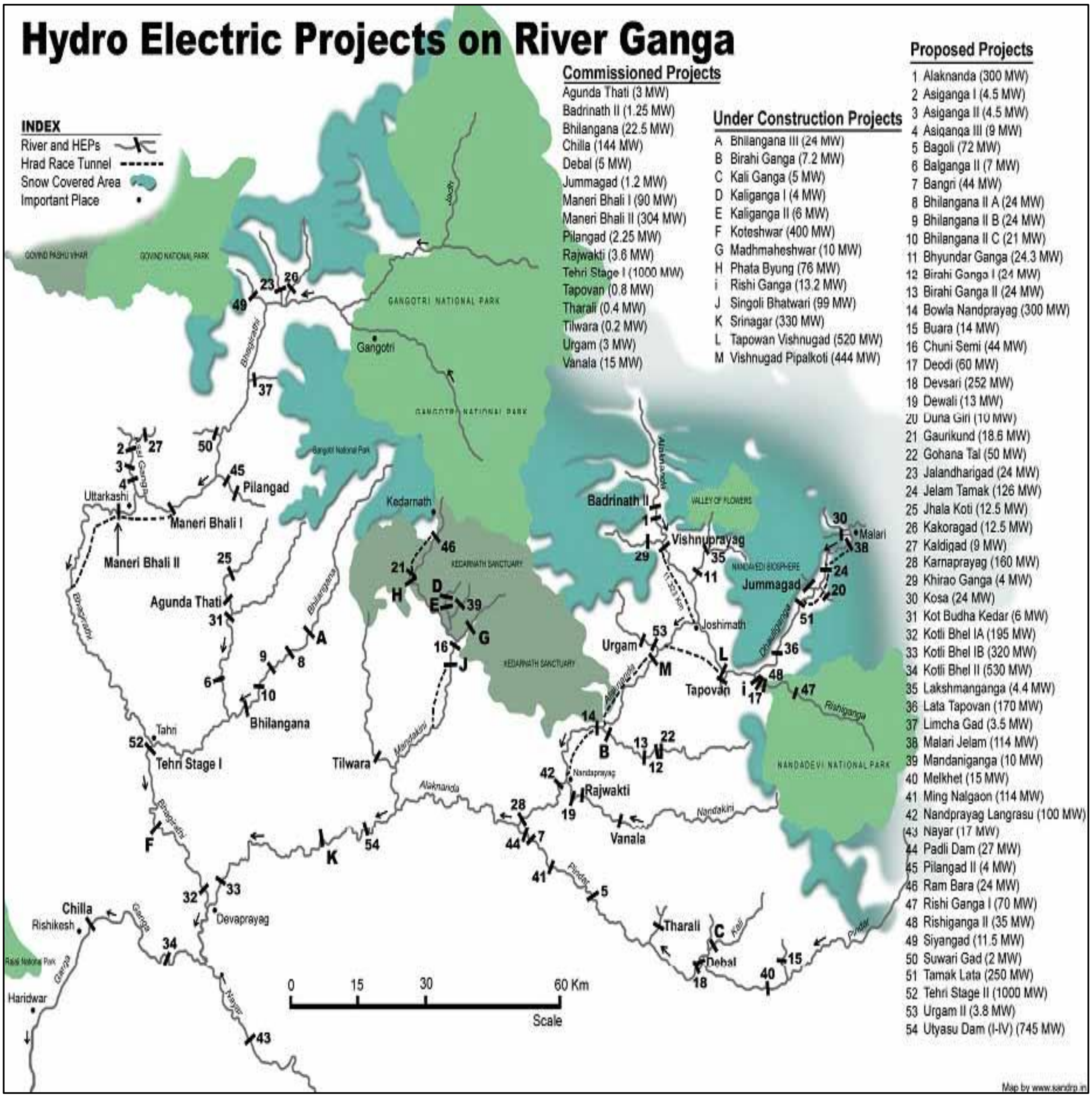


Figure 7 Some of the DAMs in Uttarakhand state that raises the concern for maintaining appropriate E-flows in the rivers from the Himalaya (Source: www.sandrp.in)

5. RECONSTRUCTION STRATEGY

Understanding the nature of disaster risks through hazard mapping is of paramount importance for disaster risk management and disaster resilient development planning, and requires a detailed mapping and modeling exercise that includes climate change projections. The key is really to understand the nature and geographical distribution of risk and expected damages and to incorporate these risks into planning, design, specifications of infrastructure assets. Making these risk maps available to the public in conjunction with training can improve widespread understanding and is the first step towards planning a strong reconstruction strategy.

The impact of post-disaster reconstruction on affected communities' livelihoods and on their resilience to future disasters cannot be analyzed immediately after the reconstruction period is over. Yet, much research draws conclusions about the appropriateness of various reconstruction approaches based on research carried out during or shortly after their implementation. Significantly less attention has been given to the long-term changes triggered by reconstruction, and on whether the vulnerability of the concerned communities to eventual future disasters is indeed mitigated.

The reconstruction strategy has to look into the nature of the high vulnerability of mountain communities. Key activities that should be undertaken include:

a. supporting sustainable agricultural, pasture and forestry practices in mountain areas as a key element of disaster risk reduction for both upland and lowland communities;
b. carrying out baseline vulnerability studies in mountain community areas using gender analysis to ensure that disaster risk reduction initiatives and emergency relief and rehabilitation efforts target those most at risk;
c. increasing awareness and developing integrated strategies and policies on disaster risk management at the national level;
d. integrating local environmental knowledge and community memories in disaster risk reduction strategies.
e. increasing capacity building in all the elements of disaster risk management, including preparedness, mitigation, response and rehabilitation;
f. facilitating mountain communities access to resources through several tools such as microcredit and banking, non-farm income opportunities, as well as disaster mitigation strategies that offer payments to mountain communities;
g. The reconstruction of Uttarakhand will have to be:
    - state-led and build upon local capacity with "build back better" approach
    - comprehensive and integrated into the local economy and livelihood regeneration
    - coordinated with the resources of the state and local knowledge
    - sustained and accountable to:
        - Roads and bridges that are reconstructed with new technologies and knowhow
        - Hill area infrastructure that are to be reconstructed and upgraded
        - Tourism Infrastructure and trekking routes rehabilitated and reconstructed
        - Bring forth improved capacity on disaster preparedness and management.
        - Ensure community participation in all aspects of development, including those managed by outside agencies and private contractors.

Realizing that heavy rain fall in Uttarakhand has caused extensive damages along the river courses and the extent of devastation became widespread due to landslides, the following sections present some of the example of landslides stabilization measures by innovative techniques, including bio-engineering solutions, followed elsewhere in the country and abroad. Anthropogenic hazards play an important role towards the risk factor of the region. Being an important pilgrim destination, the region is facing high influx of human and vehicles seasonally. Hence, high pressure on natural resources creates an imbalance in ecology and environment. To cater the huge seasonal pilgrim pressure; roads, bridges, hotels, guest houses and other constructions related to hospitality and support services throughout the year, certainly put pressure on the natural equilibrium in terms of land use change, land degradation, over exploitation of water resources etc.

The accelerated pace of erosion in this geo-dynamically sensitive region coupled within supportably big growth in human and livestock. (Pal, et. Al, 2014). Majority of the tributaries in the watershed are seasonal in nature and major tributaries and small rivers are perennial in nature. Therefore, the flow of water in the river basins or throughout the watershed is not uniform or steady. Due to the unpredictable water level rise during monsoon or during heavy rainfall in the region, it is quite challenging to alert and evacuate the people from the area of probable inundation. With the limited data and documentation, Pal et. al (2014) attempted to identify the potential hazard zone for the cloudburst and flash flood hazard in the Asi Ganga River basin along with a part from the Bhagirathi river basin. The identified vulnerable zone is useful for the administrators and policy makers to prepare effective evacuation plan and disaster management plan.

District administration and non-governmental organizations (Pant and Pande, 2012) are taking few steps towards the mitigation and preparedness for earthquake, landslides and forest fires by means of imparting training to the officers and communities, distribution of posters, brochures and pamphlets etc. Advance stock of food grains, fuel and other essential commodities are done by the district administration keeping in mind the previous experiences. Being situated at the higher elevation, the district is infested with number of watersheds.

6. INFRASTRUCTURE RESTORATION

All reconstruction projects must be cost-effective, be both engineering and technically feasible, and meet environmental planning and heritage preservation requirements of the nation.

Some of the important facts based on which entire reconstruction program requires to be streamlined are:

a. Uttarakhand has a total area of 53,484 km², of which 93% is mountainous and 64% of which is covered by forest. Most of the northern part of the state is covered by high Himalayan peaks and glaciers, while the lower foothills are densely forested. Tectonically the state is very much susceptible to earthquake, landslides, flash flood and forest fires. While taking up reconstruction work the authority has to look into the hazard and vulnerability profile of the state
b. Landslides, which are mostly happening along the non-engineered hill roads or areas where drainage control measures are not effective or in places where pre-existing sliding mass gets aggravated due to rainwater infiltration; have been found contributing more to soil erosion and siltation in river valleys. How landslides can be prevented by advanced techniques available in the country so that road communication remain intact during emergency operation in the hill areas of Uttarakhand
c. Deforestation is often blamed for landslides, but accountability of the same has to be critically examined by expert group. Possibility of innovative bio-engineering measures for slope stabilization, while keeping in view of the conventional practices followed in the hill area development so far.
d. While DAMs are needed to meet energy and economic development requirements of the nation, building them in the eco-sensitive areas of Uttarakhand is a construction-intensive activity involving blasting, excavation, debris dumping, movement of heavy machinery, diversion of forests and rivers. Such activities cumulatively impact mountain ecology of Uttarakhand and for this what kind of 3rd party assessment to be initiated by State Govt and MoEF

e. The Uttarakhand state needs to come up with an action plan to save its mountain ecosystem vis-à-vis "Char Dham" tourism infrastructure networks, in which mountain people's livelihood is to be looked into. How newly established "Uttarakhand Reconstruction Authority" shall regulate pilgrims, guide Dams carefully built and aim for sustainable development.
f. Implication of heavy rainfall warning by the nodal weather forecasting agency of the country and nation's capability to know precondition before "heavy rainfall" in Uttarakhand have become crucial issues. Mere deployment of advance weather forecasting system in the region may not suffice the need of the affected society until country's knowledge institution work together to devise "cloud burst" forecasting system. It's required to identify the gap between theory and practice in weather modelling by making scientific research more relevant to decision makers and for those agencies involved in post-disaster reconstruction and risk reduction.
g. Realising that high population densities living in informal and highly vulnerable settlements in hill areas of Uttarakhand - how effectively the benefits of participatory and owner-driven reconstruction process be initiated for Uttarakhand through various rural reconstruction programs, where social networks are stronger, and innovative building technologies are affable to construction workers.
h. The seismic fault-lines of this earthquake-prone state were not kept in mind while building roads and other infrastructure. These tectonic fault-lines have been cut for roads where seismic movements in the fault-lines are to be accounted for.

6.1 Roads and Slopes

The non-engineered roads construction practices in most of the damaged areas in Uttarakhand and roads conditions seen before the heavy rain often corroborates that rain fall is the main reason for landslides. However, in some of the cases, utmost care is taken to maintain atleast a healthy drain system along the road but the same is not continued routinely for majority. It is true that the state is located in the midst of young and unstable mountains and the area is subjected to intense rainfall but neither of these characteristics can cause substantial damage to the roads/infrastructure, if they were constructed following technical guidelines available in the country. The landslide problems around the Monsoon occur not because of the steep slopes, but because no attention is paid to the stabilization of roads and its allied components in scientific manners. Some of the perennial landslides problems in India have been tackled by Border Roads Organization (BRO) well.

While in the neighboring state of Himachal Pradesh in India, Himalaya, taking advantage of the hard rocky strata, roads infrastructure created decades ago (Figure 8) have been functioning well, the long term performance of these roads requires continuous monitoring. Geotechnical intervention in such road networks are minimal and hence in the reconstruction phase of the post-flash flood due importance are to be accounted for.

Figure 10a shows the disruption of the roads in Uttarakhand and defying the role of proper placement as well as proper maintenance of cross drainage. As a recovery measure for such situation, Figure 10b, shows one of the ways to to look into such problems.

Figure 11a, shows one of the severe landslides in Uttaarakhand state that remained unsolved by simple measures of slope protection, e.g. retaining walls, gabion mat, soil nailing, etc. The reality mitigating such slopes by multi agency and multi-objective control measures is shown in the Figure 11b.

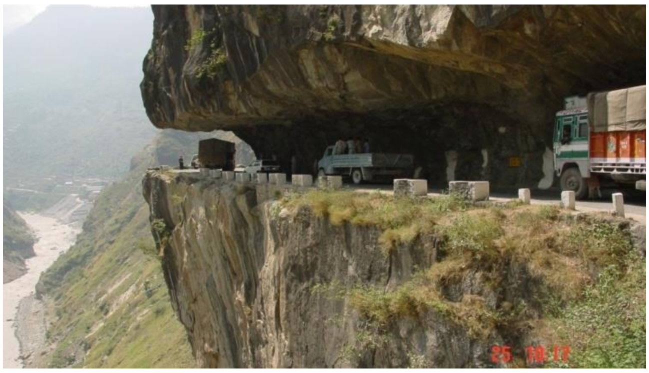
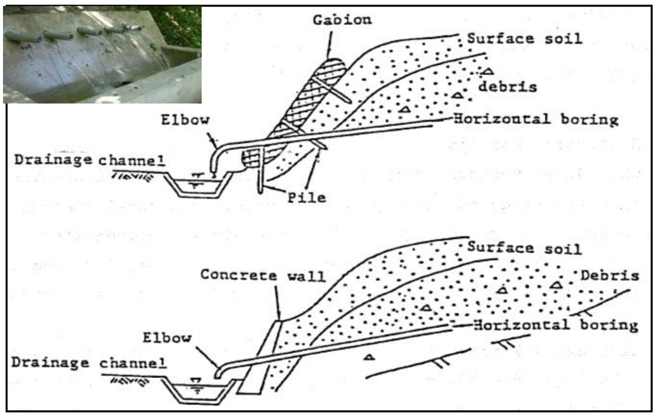


Figure 8 Road construction on rocky mountain in Himachal Pradesh, India remain undisturbed till stability of the rocks are tested by earthquakes and other hazards in the vicinity

Figure 9a shows one of the many roads in the hilly areas that goes out of order due to poor drainage resulting that they require proper geotechnical measures. In many cases such problems, can be mitigated by providing perforated drains as shown in Fig. 9b and the drained water can be tapped for other uses (inset Figure 9b).

(a)



(b)

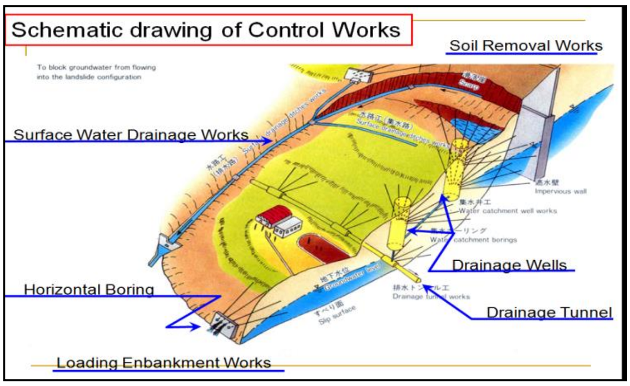
Figure 9 Incipient cross drainage due to heavy rain fall during Uttarakhand flash flood (2013) and suggested simple correction measures by inclined drain. Inset image showing application site of the same

(a)

(b)

Figure 10 Torrential water flow severed the road link thus disrupting the communication. Lots of debris and muck formed out of flash flood might have caused such problems, for which adequate culvert or aqueduct were not in place. Suggested restoration measures with Geo-net protecting the culvert

(a)



(b)

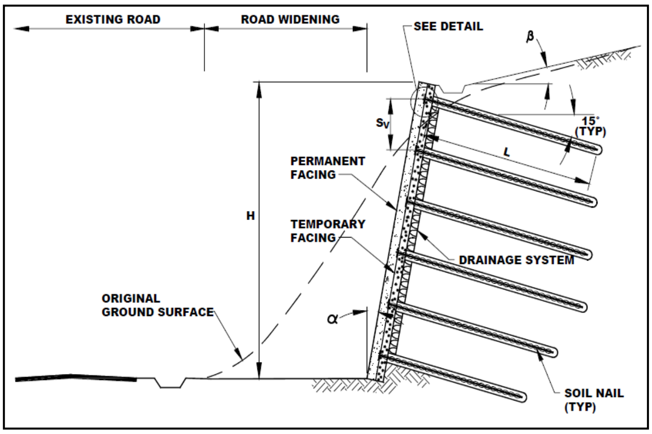
Figure 11 (a) Typical facets of fragile slope in Uttarakhand state and multi-purpose and (b) multi-objective of typical slope stabilization in Japan (Source: Ministry of Land, Infrastructure, Transport)

6.2 Modern slope stabilization measures

While flash flood induced geotechnical failures were found in plenty in the state of Uttarakhand, it's also important to be aware of the typical stabilization measures for normal slopes, some of which are exemplified in Figures 12 to 18.

Use of rubble masonry is a routine practice in the hill roads (Figure 12a) and vulnerability of such type of protection measures especially during heavy rainfall requires no special mention. However, typical soil nailing option as shown in Figure 12b or for some of the ongoing National Highways construction in the neighbouring state of Himachal Pradesh, where massive rouble masonry wall constructions are followed (Figure 13a), application of nailing technique followed elsewhere (Fig. 13b), can be adopted for the reconstruction hill slopes ravaged the flash flood in Uttarakhand. In Figure 14a, slope protection measures taken as such can be made performing better during heavy rain fall by application of geonet or geogrid as typically shown in Figure 14b. Even in some of the convention rubble masonry slope protection walls as shown in Figure 15, the inclination of the week hole pipes, go out of order due to poor maintenance. In such cases composite geosynthetics layers can be used to keep drainage operational during extreme weather events.

(a)



(b)

Figure 12 Conventional method of Stone masonry wall (a) vs. Soil nailing (b) that typically used for stabilizing slopes

(a)

(b)

Figure 13 Typical road side hill slope protection measure in hilly areas vs. Nailed slope in Japan

(a)

(b)

Figure 14 Unprotected slope vs. Protection by geo-net

Figure 15 Provision of weepholes in normal construction and ill performance due to poor maintenance

Many Dams during flash flood, went out of order due to excessive erosion and water currents. The documentation of the damages and loss has not been done yet but in the case of one Dam, which was newly built and yet to start operation (Figure 16a) at the Srinagar town of Uttarakhand, it has removed the silts deposit about 200m away downstream due to release of water through sluice gate and thus filled up valley town with 2 to 5m thick silt load as shown in Figure 16b. As many of the existing building in the Srinagar town, came under silt, during reconstruction densification of the same can be achieved by geosynthetic vertical drains.

(a)

(b)

Figure 16 Silt deposit at Srinagar, Uttarakhand due to water release by the Dam

6.3 Bio-engineering measures

Realizing that heavy rain fall induced flash flood carries everything that come on its way; it's high time to look into the reconstructions measures that must be sustainable. It is very much possible to adopt slope stabilization measures by combination of reinforced earth, soil nailing, etc technique with bio-engineering measures by Vetiver grass (Truong and Baker, 1996; Dalton et. al, 1996). Climate change/extreme weather phenomena and impact of deforestation and changes in the flora-fauna of mountains, possibly due to multipurpose hydro power projects and other tourism-driven vulnerable establishments along the towns and river banks needs to be assessed. Though it's not yet possible to bring all climate related facts into one fold and justify the cause-effect role, at least reconstruction measures can take care of the landslides and erosion control measures by local yet simple techniques. This section provides the application of Vetiver grass, which is primarily of Indian origin, but routinely used by more than 120 countries. Some of the potential applications in the North East part of India wherein proper methodologies along with some successful examples are explained.

6.3.1 Application areas:

a. Landslides scenario in the country – highlighting ineffective/inadequate drainage/stabilisation measures that leads to progressive failure
b. Hill widening by cutting hills vs. man-made landslides
c. Live landslide hotspots vs. inappropriate technological overtures
d. Landslides prevention measures by conventional slope stabilisation methods, such as gravity retaining walls vs. modern techniques using geosynthetics
e. Important hill roads where slope stabilization measures are taken with extremely high cost vs. bio-engineering measures ensuring better safety with low or no cost
f. Vetiver grass – it's origin, properties and potential for erosion and landslide control
g. Successful Application of Vetiver grass where conventional or many other methods failed but Vetiver caused complete solution with hardly any cost and maintenance
h. Application of Vetiver grass – giving examples of successful and failed application in India/abroad and signifying the role of Vetiver grass for long term solutions
i. Guidelines for Vetiver application siting several examples of landslides hotspots exclusively or in combination with conventional slope retaining structures

Excepting a mere mention in the recent Indian Road Congress (IRC) code for the application of Vetiver system, many nodal organizations in the country are hesitant to adopt Vetiver system (VS). However, a combination of modern techniques with Vetiver system has to be emphasized and in order to harness that geo-professional practices need to evolve technique to apply bio-engineering solution in soil erosion and landslides problems. Following considerable research and the successes of the many applications presented elsewhere, it is now established that Vetiver, with its many advantages and very few disadvantages, is a very effective, economical, community-based and environmentally-friendly sustainable bioengineering tool that protects infrastructure and mitigates natural disasters. Once established, the Vetiver plantings will last for decades with little, if any maintenance. However, it must be stressed that the most important keys to success are good quality planting material, proper design, and correct planting techniques.

6.3.2 Characteristics of Vetiver system

Vetiver's unique attributes have been researched, tested, and developed throughout the tropical world, thus ensuring that Vetiver is really a very effective bioengineering tool:

- Although technically a grass, Vetiver plants used in land stabilisation applications behave more like fast-growing trees or shrubs. Vetiver roots are, per unit area, stronger and deeper than tree roots.
- As strong as or stronger than those of many hardwood species, Vetiver roots have very high tensile strength that has been proven positive for root reinforcement in steep slopes.
- These roots have a mean tested tensile strength of about 75 Mega Pascal (MPa), which is equivalent to 1/6 of mild steel reinforcement and a shear strength increment of 39% at a depth of 0.5m

Typical man-made slope instability problems created during hill road widening process, for which conventional solution is not either possible or economically feasible (Figures 17a and b) can be stabilized by combination of small height breast wall and Vetiver plantation as shown in Figure 18 a and b.

(a)

(b)

Figure 17 Stabilisation measures for natural and man-made cut slope in hill areas in Uttarakhand await geotechnical intervention

The feasibility planting vetiver grass even in the 90^o angle hill cut is possible and the stability of such slopes are exemplified. In order to propagate this technique, a good deal studies, specially suitability of the Vetiver grass at different geo-climatic conditions are to yet to catch the Geo-professional domain studies and rightful practices to solve many unsolvable slope stability problems by conventional methods. But the wide scale erosion due to flash flood in Uttarakhand (Figure 19a) and potential danger awaiting for the India's highest Dam constructed decades back in the same state (Figure 19b), where hydroelectric power generation is often limited by the fast drawdown induced erosion are yet to be tackled by the current geotechnical practices in the country.

(a)

(b)

Figure 18 Typical application of Vetiver grass in the State of Assam, India as a viable cost effective alternative for slope stabilization

(a)

(b)

Figure 19 Some of the unsolved slope and erosion areas in Uttarakhand (a) along the Mandakini river and (b) Tehri Dam reservoir

7. CONCLUSIONS

An effective reconstruction program for the Uttarakhand is required for rebuilding state economy and reducing financial and societal interruptions. Reconstruction works must start with the geotechnical evaluations to identify vulnerable establishments in the State by initiating damage surveys and looking into the erstwhile design practices, construction methods, and building materials that either failed under the forces generated by the heavy rain fall induced flash flood or were successful in resisting such forces. In addition, the reconstruction efforts should also look at land use management and planning practices, as well as natural/man made hazard identification and risk assessment. This is to be done in an effort to learn whether actions of the Government, other than those involved in designing and constructing buildings/dams/roads along the river valleys and temple towns in Uttarakhand are up to the mark in minimizing damages from natural hazards, including earthquakes.

For the disaster prone area in Uttarakhand, there should be always an existing emergency disaster plan for better coordination among the various agencies in the district or at the disaster. Given the current policy of the State Government of pursuing hydro-power projects, the potential cumulative effect of multiple run-of-river power projects can turn out to be environmentally damaging but it's urgently required to have technical auditing of these projects. The impact of environmental concerns required to be assessed by geo-professionals, for which Indian Government has to device policy frame work beyond the jurisdiction of normal EIA procedure that not feasibly accountable for the damaged caused by recent flash flood.

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