

The Uttarakhand Himalayan region of Yamunotri and Janki Chatti is ripe for a catastrophe similar to that which befell Kedarnath in 2013.

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Abstract

Yamunotri is a holy Hindu pilgrimage site in the northern Uttarkashi district of Uttarakhand Himalaya, India. It is located in a small 'V' shaped valley on the left side of the Kalindi River. During the months of May through October/November, this temple sees tens of thousands of visitors. The National Highway from Rishikesh to Yamunotri ends at Janki Chatti. The 6-kilometer pony ride from Janki Chatti to Yamunotri follows the right bank of the Yamuna River. At Yamunotri, the Yamuna is known as Kalindi. The pony route from Janki Chatti to Yamunotri includes stops at Ram Mandir and Sita ki Vatika. The upper Yamuna valley in the Yamunotri - Janki Chatti area is very similar to the upper Mandakini valley in the Kedarnath - Gaurikund area in terms of its

physiography, geomorphology, geology, and orography, suggesting that future torrential rains may cause a Kedarnath-type disaster in the Yamunotri - Janki Chatti area, where almost all the settlements are located close to the river. Janki Chatti, located downstream of Kharsali bridge on the right bank of the Yamuna, is a popular parking spot, despite being just a few meters above the water and so encroaching towards the river's active flood plain. The downstream communities of Saina Chatti, Kharadi, and Gangani are vulnerable to harm from flash floods in the upper Yamuna valley because they are situated on the historic flood plain and lower terraces of the Yamuna River.

Keywords: *Himalaya, India, Satellite Image, Deluge, Hazard, Vulnerability, Risk, Disaster.*

1. Introduction

High floods in the Yamuna River (called the Kalindi in Yamunotri) may wipe out Yamunotri, Ram Mandir and Janki Chatti in Uttarkashi district of Uttarakhand Himalaya in a way similar to the floods in the Mandakini River in June, 2013 wiped out Kedarnath, Rambara and Gaurikund in

Rudraprayag district of Uttarakhand Himalaya (India), claiming thousands of lives in one of the worst Himalayan floods in history (Uniyal, 2013; Vermaet et al, in press) (Figure 1a,b,c,d,e,f; 2a,b,c). In Yamuna valley Janki Chatti is the entrance point of the 6 km long pony route to Yamunotri and is very similar to Gaurikund which used to be

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the entry point of the 14 km long pony route to Kedarnath prior to the June, 2013 deluge. Ram Mandir is a transit point on the Janki Chatti - Yamunotri pony route similar to Rambara on the Gaurikund - Kedarnath pony route. According to Jain et al (2007) the source of the Yamuna River is Yamunotri Glacier. Champasar Glacier located on the Kalind Mountain at a height of 4,421 m above sea level, about 1 km further up from Yamunotri shrine, has also been referred to as the source of the Yamuna River (<http://en.wikipedia.org/wiki/Yamunotri>) (Figure 2a). This is similar to the Kedarnath area which is drained by the Mandakini River which originates from the Chorabari Glacier (Dobhal et al., 2013) (Figure 1a).



Figure 1a: 3-Dimensional view based on a satellite image of Kedarnath area (after www.earth.google.com; Image ©2008 DigitalGlobe; Europa Technologies; Terra Metrics).



Figure 2a: 3-Dimensional view of the upstream area of Yamunotri based on a

satellite image (after www.earth.google.com; Image © 2014 CNES / Astrium © Mapabc.com US Dept of State Geographer).



Figure 1b: Pre disaster satellite image of Gaurikund (after www.earth.google.com; Image © 2013 DigitalGlobe).



Figure 2b: Satellite view of Janki Chatti and Kharsali (after www.earth.google.com Image © 2014 CNES / Astrium © Mapabc.com US Dept of State Geographer).

2. Data and Methodology

This study is based on frequent field visits to the Yamunotri and Kedarnath area and is aimed at inferring the hazard, vulnerability and risk scenario in the Yamunotri area based on the experience of the Kedarnath deluge of 2013 and prevailing similarities between these two areas. Comparative examination of satellite images (downloaded from Google Earth) has helped in simulation

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the similarities in terrain conditions, geologic and geomorphologic setup, orographic control, anthropogenic activities and overall hazard and vulnerability status of the Kedarnath - Gaurikund area both before June 16th, 2013 and the present day Yamunotri - Janki Chatti area, an attempt has been made to indicate the possibility of a Kedarnath - type deluge in the Yamunotri - Janki Chatti area in the future.



Figure 1c: Pre disaster satellite image of Kedarnath (after NRSC website bhuvan-noeda.nrsc.gov.in).



Figure 1d: Post disaster satellite image of Kedarnath showing devastation by flash flood and attendant debris flow (after NRSC website bhuvan-noeda.nrsc.gov.in).

3. Results and Discussion

3.1 Hazard and Vulnerability Status

According to Biyani (2002) and Uniyal et al (2012) the upper Yamuna river valley

witnesses active tectonics and high seismicity. Further, these phenomena in conjunction with high rainfall coupled with hill slope toe erosion drastically enhance the probability of large landslide events in this part of the river valley. Uniyal et al (2012), reported an active translational rock slide about 50 meters upstream of Yamunotri temple on the left bank valley wall of the Yamuna River in an area where the river flows through a narrow gorge. Further activation of this slide zone and other such active slide zones upstream of Yamunotri Temple might block the flow of the river and this in turn may result in the creation of a lake immediately upstream of Yamunotri Temple (Figure 2d).



Figure 2c: Satellite view of Yamunotri (after www.earth.google.com ; Image © 2014 CNES / Astrium © Mapabc.com US Dept of State Geographer; 'X' is showing location of temporary shops, 'Y' is showing the location of bridge & 'Z' is showing the location of Kali Kambli Dharamshala the only lodge in Yamunotri.

The outburst of such a lake in turn could pose a great risk of flash flood hazard to Yamunotri Temple and the downstream areas of Ram Mandir, Sita ki Vatika and Janki Chatti etc. This is possible in the future since, on the basis of investigations by Dubey et al (2013) on orographic control of the Kedarnath disaster, it can be inferred that Yamunotri also seems to fall in the same orographic region as Kedarnath and hence,

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Yamunotri is also prone to high rain fall and has more or less similar hydrometeorological conditions. According to the Vulnerability Atlas of BMTPC (2005), this area falls in Earthquake Very High Damage Risk Zone V. This enhances the probability of earthquake induced landslides in the area. The rock fall zone at Yamunotri Temple is presently deactivated due to treatment of the hill slopes of Kalind Parvat immediately upslope of the Temple. However, torrential rain, cloud burst or a major seismic event may again activate this critical hill slope (with fragile and highly jointed rocks). The active slide zone at the Ghur Parav area of Yamunotri is virtually a death trap for the pilgrims (Uniyal et al., 2012).



Figure 2d: Active landslide on the left bank valley wall of the Yamuna River about 50 meters upstream of Yamunotri Temple.

3.2 History of Extreme Weather events

Both the upper Mandakini and upper Yamuna valley have witnessed extreme weather events in the form of prolonged torrential rains during past decades. This is

evident by devastating landslide events that claimed more than 100 lives on 18-19 August, 1998, in the Madhyamaheshwar and Kali Ganga river valley (tributaries of the Mandakini river), and a major landslide at Phata (about 15 km downstream of Gaurikund) during the torrential rainfall of 16 July, 2001 and finally the devastation of 16-17 June, 2013 in the Kedarnath - Gaurikund area that took a very heavy toll of human lives in the Kedarnath area in the Mandakini valley (Sati & Sundriyal et al., 2006; Asthana & Shah, 2007; Uniyal, 2013; Verma et al.).

During the torrential rains of the year 2013 at the time of the Kedarnath deluge in Mandakini valley the River Yamuna at Yamunotri also flooded and altered its course and damaged the base of the side wall and railing of the Yamunotri Temple (www.dailymail.co.uk & www.tribuneindia.com/2014). This in turn resulted in a debris flow and hill slope toe cutting in the area close to Yamunotri temple and the sacred bathing complex around the hot spring (Champati Ray et al., 2013).

In the upper Yamuna valley the Saina Chatti landslide (with funnel shaped scarp and elongated lobe) some 18 km downstream of Janki Chatti, is an evidence of torrential rainfall induced landslides (Figure 2f). Lack of instrumental rainfall data makes it difficult to authenticate whether this (Saina Chatti) landslide is cloud burst induced or not. However, discussion with locals in Saina Chatti confirmed heavy rains during this slide event. The above evidence of extreme weather events in the Yamuna valley during the recent past indicates a strong probability of torrential rains or even cloud burst induced devastating flash floods and landslides in the Yamunotri - Janki Chatti area and downstream areas of Saina Chatti, Kharadi and Gangani which are located on

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very high flood hazard prone old flood plain and lower terraces of the upper Yamuna River valley. Yamunotri Temple is presently witnessing toe erosion by the Yamuna River and, to mitigate it, wire crates and large cement blocks have been placed on the river side of the temple. This temple is similar to a four to five storied building constructed on the lower terrace or old flood plain of the River Yamuna that may be flooded again in near or far future (Figure 2h).

downstream of Yamunotri) in close proximity to the Yamuna River and also the uncontrolled floating population of pilgrims has drastically increased the vulnerability of Janki Chatti (Figure 2b & j).



Figure 2f: Torrential rain fall induced Saina Chatti landslide in upper Yamuna valley.

Construction activity at Yamunotri during recent times has transformed it from a shrine with no construction to one with ill conceived constructions and this in turn has drastically enhanced the physical vulnerability of Yamunotri shrine to flash floods, landslides and earthquakes (Figure 2g & h). At Yamunotri the 'V' shaped narrow valley with unstable hill slopes provides, virtually no spare space for further construction (Figure 2e). Rampant construction activity for commercial purposes in the Janki Chatti area (some 6 km



Figure 2g: No construction activity in Yamunotri as depicted in 1820 by James Baillie Fraser (<http://en.wikipedia.org/wiki/Yamunotri>).

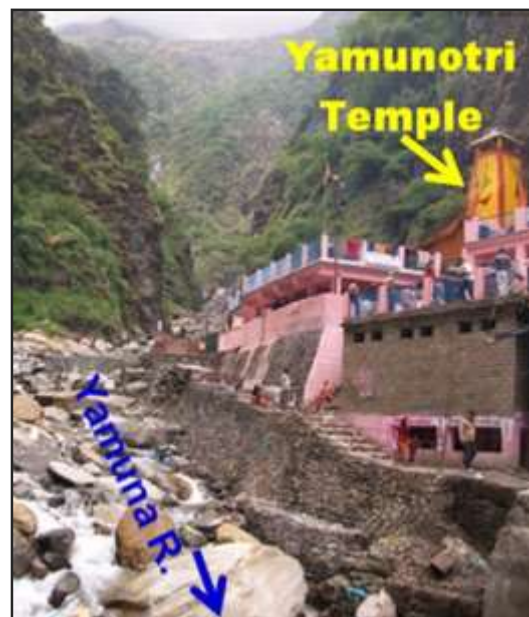


Figure 2h: Present day field view of Yamunotri Temple.

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3.3 Similarities between terrain conditions of Kedarnath and Yamunotri :

Kedarnath and Yamunotri both lie in the higher Himalaya and are in the vicinity of the Main Central Thrust (MCT), that separates the higher Himalaya from the lesser Himalaya. Both the Kedarnath - Gaurikund and Yamunotri - Janki Chatti areas are geodynamically unstable with neotectonic movements and high frequency of landslides including rock falls, debris flow and ground subsidence. The geological set up of the Rambara - Kedarnath area is defined by the higher Himalayas comprising high grade metamorphic rocks of the central crystalline zone (referred to as upper crystalline rocks). The Vaikrita Thrust (MCT1) north of Gaurikund separates the high grade upper crystalline rocks of the Rambara - Kedarnath area from the lower crystallines of Gaurikund - Sonprayag - Okhimath area. The geological set up of the Gaurikund area is defined by biotite sericite garnetiferous schist (Naithani and Prasad 1997). Further, upstream of Gaurikund and north of the Vaikrita Thrust (MCT1), upper crystalline marble and garnetiferous mica schist are exposed. Further, north in Jungal Chatti and to the south of Rambara, biotite gneiss with marble are exposed. The area from north of Rambara to the south of Kedarnath comprises kyanite biotite garnetiferous gneisses with basics. The area around Kedarnath and immediately north comprises garnet bearing augen gneiss and further north around Kedar dome silliminite gneiss, quartzite and marble have been reported by Naithani and Prasad (1997). The geological setup of the Janki Chatti - Yamunotri area is defined by mylonitised quartzite, granite, gneiss, green schist metapelites and phyllitic quartzite of Yamuna Formation and intrusive metabasic rocks of higher Himalaya. Quartzite and marble of the Paligad

Formation are also exposed within the Yamuna Formation at Janki Chatti and Yamunotri . Crushed breccias and small outcrops of gouges are also exposed at some places between Janki Chatti and Yamunotri (Biyani, 1998; 2002). The Vakrita thrust in the Yamuna valley lies between Janki Chatti and Yamunotri. Biyani (2002) reported the Yamuna Sinistral Tear, a prominent first order transverse slip fault along the Yamuna River with about 100-200 meter strike displacement. Highly jointed, fractured, sheared and even crushed and crenulated rocks at some places between Gaurikund - Kedarnath as well as at Janki Chatti - Yamunotri make the critical slopes of these areas unsuitable for slope cutting and overloading by construction of buildings. Geomorphological similarities between Gaurikund - Kedarnath and Janki Chatti - Yamunotri are evident by highly dissected denudostructural hills (in both areas) separated by narrow and steep 'V' shaped tectonically controlled valleys (Uniyal, 2013; Biyani, 1998). Further, the Mandakini valley in the Gaurikund - Kedarnath area and the Yamuna valley in the Janki Chatti - Yamunotri area have conspicuous gorges and are drained by snowmelt fed highly turbulent rivers Mandakini and Yamuna respectively. The active seismotectonic regimen of the Janki Chatti - Yamunotri area can be attributed to the neotectonic deformation that this area is experiencing. This is evident by Yamuna Sinistral Tear, a water fall in the Kalindi valley about 500 meters north of Yamunotri, a rapid near Yamunotri, hot water springs at Yamunotri and Janki Chatti and cold water springs all along the valley and raised terraces at Kharsali (opposite to Janki Chatti) with valley ward margins of the terraces characterized by a number of active debris flow slides

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more or less parallel to each other (Biyani, 2002; Uniyal et al., 2012).

The topographic similarities between Yamunotri - Janki Chatti and Kedarnath - Gaurikund can be depicted in the form of their narrow 'V' shaped valleys with moderately steep hill slopes and high gradient of both rivers (the Yamuna as well as Mandakini). Further, both river valleys witness heavy rainfall during the monsoon season. The hydro-geological and hydrometeorological scenario in the upper Yamuna valley bears some resemblance to the Kedarnath area and further, the narrower width of the Yamuna valley and probability of landslide damming and lake formation are even more than in the Mandakini valley (Figure 1a; 2a, c & d). This keeps alive the possibility of a Kedarnath like flash flood coupled with debris flow and or mobilization of glacial material, in the case of an extreme climatic event such as torrential rains in the upper catchment of the Yamuna River (Figure 1e,f; 2e,h).



Figure 1e: May, 2013 Pre disaster Panoramic view of Kedarnath some 20 days before the tragedy (Photograph by class xth student Ashutosh Tripathi).

The width of the Yamuna valley at Yamunotri is less than half that of the Mandakini valley at Kedarnath. Hence, the river valley at Yamunotri is very narrow to accommodate

the unremitting spate of the Yamuna River (in the event of a major flood) and might hinder the spread of flood water, which then might rise to a high level thereby posing a severe risk to the Yamunotri Temple and the bridges immediately downstream and also to the temporary shops selling items for religious rituals at Yamunotri Temple (Figure 2c, e & h).



Figure 2e: Present day field view of Yamunotri shrine.



Figure 1f: Field view of Kedarnath after flash floods and debris flow slides of June, 2013 (after <http://www.google.co.in>; <http://blogs.outlookindia.com>).

Further downstream on the Janki Chatti - Yamunotri pony route the floating population of pilgrims is at highest risk at Sita ki Vatika (immediately upstream of Janki Chatti) where the pony route passes through a severe flash flood hazard prone old flood plain of the Yamuna River (Figure 2i).

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Many stretches of the Janki Chatti - Yamunotri pony route and a major part of the settlement of Janki Chatti are located on middle and lower hill slopes and lower terraces in close proximity to the Yamuna River and might be wiped out by the Yamuna River in a manner more or less similar to the destruction of many stretches of the Gaurikund - Kedarnath pony route along with the settlement of Gaurikund in Mandakini valley during the Kedarnath deluge of June, 2013 (Figure 2b). Further, the vehicle parking at Janki Chatti immediately downstream of Kharsali bridge and the nearby motor route stretch face the severe risk of getting completely wiped out during a flood event (Figure 2j). Immediately downstream of Janki Chatti the active debris slide zones developed on the left bank valley wall of Yamuna River (immediately downslope of raised terrace on which Kharsali village is located) might witness severe toe erosion in the event of high floods in the Yamuna River. This could alter the angle of repose of slide material thereby causing further steepening of hill slopes and consequent headward shift of slide scarps that might even cause subsidence of some parts of Kharsali village similar to Naitwar Bazar in the adjacent Tons valley in Uttarkashi district of Uttarakhand Himalaya (Uniyal and Prasad, 2006). Further, the merging of these slide zones owing to the head ward shift of their active scarps might result in the emergence of a large slide zone in Kharsali similar to one triggered in 2003 in Varunavat Parvat area of Uttarkashi (Uniyal, 2008). However, the raised terrace at Kharsali is vast and its hill ward parts will remain intact.

3.4 Structural and Non-Structural Mitigation Planning for the Yamunotri - Janki Chatti area:

Additional bank protection is required near Yamunotri Temple on the left bank of the

Yamuna River (Figure 2h). In Janki Chatti bank protection is required on the right bank of the Yamuna River and further downstream on both banks at Kharsali bridge and Janki Chatti vehicle parking area (Figure 2b & j). Located opposite to Janki Chatti the village of Kharsali is approximately 7 km downstream of Yamunotri and is a gently sloping spacious area on raised terrace in this otherwise narrow upper Yamuna valley. Further, Kharsali has the last helipad in the Yamuna valley and it serves as the only air link to Yamunotri (Figure 2b). Toe walls and wire crates are also required as structural mitigation measures for stabilizing the parallel and sub parallel landslide zones developed down slope of Kharsali village on the left bank of the Yamuna river. Phul Chatti - Janki Chatti stretch of the Rishikesh - Yamunotri Highway (opposite Kharsali on the right bank of the Yamuna River) needs additional protection to minimize erosion during flash floods. Critical slopes and old slide material at Ram Mandir restricts the capacity of this transit point (to Yamunotri) to accommodate the construction of restaurants.

At Yamunotri moderately steep to steep and at some spots even critical hill slopes and flash flood prone reaches of the Yamuna river hardly provide space for commercial construction (Figure 2c,d,e,h). Temporary shops near the iron bridge across the Yamuna River at Yamunotri are prone to landslides from upslope hill side and flash floods and toe erosion along the river (Figure 2c & e) and hence, should be shifted to a relatively safer site on the left bank somewhere near Kali Kambli Dharamshala (Figure 2c). Apart from this, new commercial constructions should neither be allowed around Kali Kambli Dharamshala nor on the banks of the Yamuna River immediately downstream of Yamunotri Temple. Further,

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structural mitigation measures should be taken immediately to stabilize the active rock slide zone on the left bank of the Yamuna river (about 50 meter upstream of Yamunotri Temple) in order to avoid (in the near future) obstruction of the Yamuna River and probable formation of a lake, the outburst of which would cause havoc in Yamunotri and downstream.



Figure 2i: Part of Yamunotri - Janki Chatti pony route passing through severe flood hazard prone old flood plain of Yamuna River at Sita ki Vatika (Smriti Van).



Figure 2j: Vehicle parking at Janki Chatti on the right bank of the Yamuna River on its lower terrace is at risk of flash flood.

4. Conclusion:

The Yamunotri - Janki Chatti area is prone to multihazards namely landslides, flash floods and earthquakes. Yamunotri witnessed a rock fall in 2004 and is also prone to flash

flood and bank erosion by the Yamuna River (Uniyal, 2013; Champati Ray et al., 2013; Uniyal et al., 2012). Further, some stretches of the Janki Chatti pony route and parts of the Janki Chatti immediately down slope of the pony route are prone to subsidence, bank erosion and flash flood. Feasibility of a rope way as a safer means of transport along the 6 km distance of Janki Chatti - Yamunotri should also be assessed. Further, the possibility of construction of emergency shelters at Kharsali village should be explored as part of an effective disaster response strategy for this area since this village is located on a raised terrace and is the last air link to Yamunotri. However, a rope way between Janki Chatti and Kharsali is also required as a means of emergency transport since the existing iron bridge between these two settlements might be wiped out during a major flood. Rana Chatti (few km upstream of Saina Chatti) seems to be another safe site for emergency shelters as it is at a flood safe location on Yamunotri Highway.

Unlike at Kedarnath, there are fewer elements at risk in Yamunotri since there are only a few shops and a dharamshala at Yamunotri and the majority of the pilgrims ensure a return journey to Janki Chatti on the same day. Hence the vulnerability status of Yamunotri is less as compared to Kedarnath. Further, the Ram Mandir locality on the Janki Chatti - Yamunotri pony route has some temples and huts only with no lodging facility. Contrary to Kedarnath the holy shrine of Yamunotri has very limited commercial construction and the present level of commercialization in Yamunotri is more or less similar to what Kedarnath had in late sixties and early seventies when only Garhwal Mandal Vikas Nigam Tourist Banglow was there (at Kedarnath) yet, the vulnerability of floating population of

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pilgrims, shopkeepers, priests, porters and coolies etc is very high to any deluge. It would be easier to restrict further commercialization of Yamunotri as compared to other major shrines of the Uttarakhand Himalaya such as Gangotri and Badrinath which have broader valleys with road connectivity for many decades coupled with a high level of existing commercialization. Restricting further commercialization of Yamunotri would certainly lower the vulnerability of this shrine to Kedarnath like disaster in the future. Contrary to this, the level of commercialization in Janki Chatti is more or less similar to what Gauri kund (in upper Mandakini valley) had prior to the June 16th, 2013 great deluge and this drastically enhances the vulnerability of Janki Chatti to possible flood hazard in the future. Pilgrimage from Janki Chatti to Yamunotri should be in batches and be monitored by the Pilgrimage Monitoring Group (PMG) with personnel from the State Disaster Response

Force (SDRF). Further the PMG should have Quick Reaction Teams (QRTs) equipped with emergency communications, first aid and rescue equipment. Emergency shelters at Kharsali and Rana Chatti can serve as temporary shelters for accommodating stranded pilgrims and tourists in the event of temporary suspension of pilgrimage owing to bad weather conditions or a disaster situation in the Janki Chatti - Yamunotri area. There is a dire need to restrict the commercialization of Janki Chatti and relocating some of its unsafe settlements from the old flood plain and lower terraces to safer locations elsewhere, may be outside Janki Chatti, since there is no space left in Janki Chatti to accommodate any new construction.

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