Himachal Pradesh State Disaster Management Authority

District Disaster Management Authority Kullu

KULLU DISTRICT DAMAGE REPORT: TECHNICAL ASSESSMENT AND SUGGESTIONS

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Introduction

1.1 Background

The Himalayan region acts as a natural barrier and significantly impacts the climate of the Indian subcontinent, aiding Monsoon rainfall. Spanning five countries, the Himalayas are often called the 'third pole' due to their vast ice and snow reserves. As the water source for one-fifth of the global population, the Himalayas are known as Asia's water towers. Increased atmospheric moisture and energy from global warming have affected the region. Extreme disasters like cloudbursts, floods, glacial lake outbursts, and landslides demonstrate the Himalayas' susceptibility to climate change impacts. In recent years, major Himalayan River systems including the Indus, Brahmaputra, and Ganges have experienced devastating floods, landslides, and glacial lake outburst floods.

According to the IPCC report, climate change has increased the frequency and severity of intense rainfall events. In recent decades, more frequent floods have substantially damaged Himalayan communities, agriculture, and infrastructure including roads, bridges, and buildings. In 2012, flooding and breaching of Chorabari Lake devastated the Kedarnath Temple, a UNESCO World Heritage site, resulting in over 5,000 deaths. The 2021 Chamoli glacier burst disaster killed over 70 people. A 2005 Satluj river flash flood, caused by a breach in the Tibetan Parachoo lake, inflicted extensive damage, washing away 10 bridges, 11 ropeways, 15 motorable bridges, 8 jeepable and footbridges, and 10 km of NH-22 between Wangtoo and Samdo. Severe flooding in Shimla's Bhavi village on 15th August 2007 killed 58 people, reflecting Himachal Pradesh's long history of similar floods. In Himachal Pradesh, recurring cloudburst events affect some regions almost annually.

From 07-13 July 2023, very high-intensity anomalous precipitation in the Beas River basin caused devastating floods across the Manali-Kullu-Mandi region. This catastrophic event killed approximately 120 people, and damaged critical infrastructure including roads, bridges, buildings and power lines, with initial damage estimates around 967 million USD. Predicting and managing such extreme events requires comprehensively understanding their hydrometeorological precursors to develop improved region-specific early warning systems.

To analyse the causative factor behind such large-scale destruction in Kullu District, HPSDMA tasked IIT Mandi to analyse different aspects of the flood damage. IIT Mandi research Team, including 5 Faculty members from different domains and 10 research scholars, visited multiple sites across the Kullu districts and analysed the phenomenon in detail.

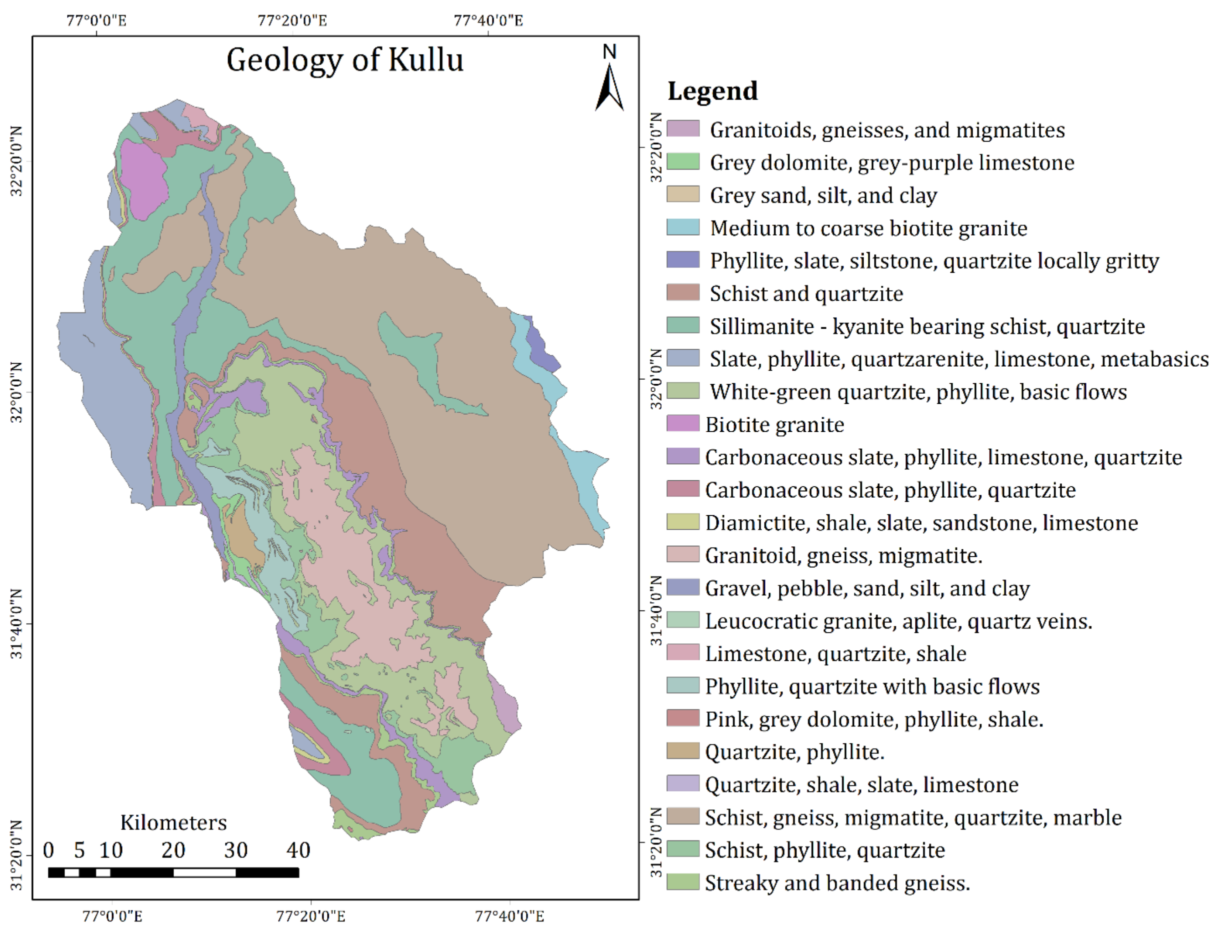
To analyse the causes behind, such large-scale floods, we analysed the hydrometeorological data collected from different sources. In the next chapter, we will discuss the data used in the study, which will be followed by the key insights generated from data analysis.

1.2 Geology of Himachal Pradesh

Himachal Pradesh, nestled in the lap of the western Himalayas, is a geological marvel that unfolds a rich tapestry of diverse formations, reflective of ancient tectonic events and dynamic geological processes. This northern Indian state is characterized by a complex interplay of rock types, tectonic boundaries, and topographical features that have evolved over millions of years. The southern part of Himachal Pradesh is dominated by the Lesser Himalayas, a geological unit comprising sedimentary rocks such as shale, sandstone, and limestone. These rocks bear witness to the intense tectonic forces resulting from the ongoing collision between the Indian and Eurasian plates. The Lesser Himalayas have experienced significant folding and faulting, shaping the undulating terrain that defines this region. As one moves northwards, the Middle Himalayas unfold, revealing a mix of sedimentary and metamorphic rocks. Slates, schists, and quartzite are prevalent, marking a history of regional metamorphism. The geological narrative becomes even more intriguing in the northernmost part of the state, where the Greater Himalayas exert their influence. Here, high-grade metamorphic rocks like gneiss and schist tell the story of the profound geological transformations that occurred during the Himalayan orogeny. Key tectonic features delineate Himachal Pradesh's geological landscape. The Main Boundary Thrust (MBT), positioned at the southern boundary of the state, marks a significant fault where the Indian Plate is thrust over the sedimentary rocks of the Himalayan foothills. Further north, the Main Central Thrust (MCT) separates the Lesser Himalayas from the Greater Himalayas, symbolizing the thrusting of crystalline rocks over sedimentary formations. The Siwalik Range, covering the foothills, contributes another layer to the geological narrative. Comprising unconsolidated sedimentary rocks like sandstone, siltstone, and conglomerates, the Shiwalik preserve fossils that provide insights into the region's paleontological past. Tertiary sediments, remnants of the ancient Tethys Sea, also make their presence felt in certain areas of the state. Granitic intrusions are widespread, contributing to the formation of Granitoid rocks, gneiss, and migmatite in various regions. These intrusive igneous formations provide a glimpse into the magmatic processes that have shaped the sub-surface geology of Himachal Pradesh. Glacial features add another dimension to the state's geology. U-shaped valleys, cirques, and moraines bear witness to the erosive action of glaciers during past ice ages. The glacial influence extends beyond the heights of the Himalayas, shaping the landscape and influencing hydrological patterns. Seismic activity is a notable aspect of Himachal Pradesh's geology, a consequence of its location in a seismically active zone.

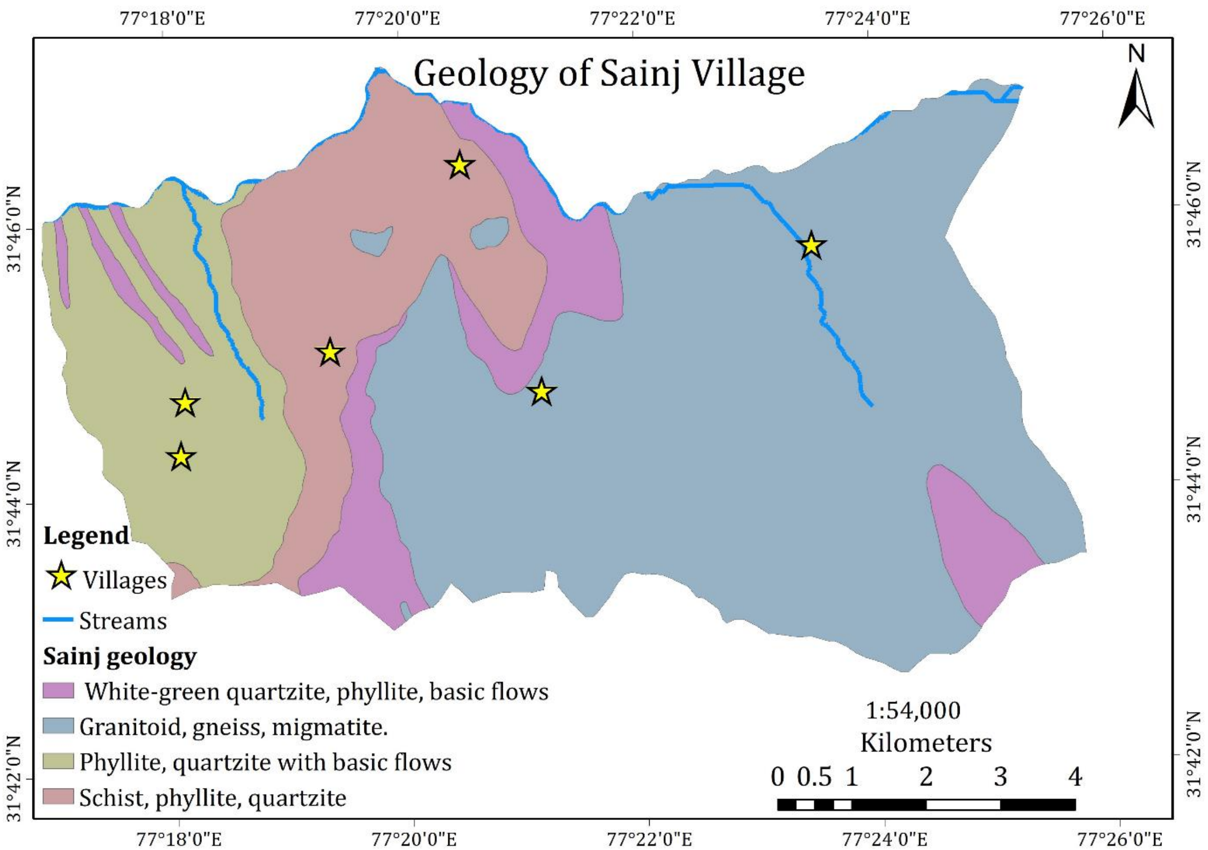
1.3 Geology of Kullu

The research area encompasses sections of SOI Toposheets, specifically No. 53E/1, 53E/5, 52H/04, and 52H/8, situated within the lesser Himalayas. Geologically, the region reveals a diverse range of rocks, spanning from undifferentiated Proterozoic to Holocene epochs, including formations such as Vaikrita, Rampur, Kullu, Naural Larji Group, Bandal Granitoid, and Quaternary deposits. The oldest rock unit in the area is characterized by Sillimanite-kyanite-bearing schist and quartzite of the Morang Formation, part of the Vaikrita Group from the Undifferentiated Proterozoic age. Within the Rampur Group, there are formations such as the Bhallan Formation (comprising phyllite, quartzite, and basic flows), Banjar Formation (consisting of schist, phyllite, and quartzite), and Manikaram Formation (composed of white-green quartzite, phyllite, and basic flows), all belonging to the Paleo Proterozoic era. The Kullu Group includes the Kharmada Formation (featuring carbonaceous slate, phyllite, limestone, and quartzite), Gahr Formation (characterized by streaky and banded gneiss), and Khokan Formation (comprising schist and quartzite). The Naural Group, dating back to the Paleo-Proterozoic era, is represented by litho units of quartzite and phyllite. The Larji Group is identified by the Aut Formation, which consists of grey dolomite and grey-purple limestone. The Bandal Granitoid, from the Neo Proterozoic era, is characterized by Granitoid, gneiss, and migmatite. Additionally, there is an Undifferentiated Quaternary deposit from the Holocene age, represented by grey fine to coarse sand with pebbles and clay.



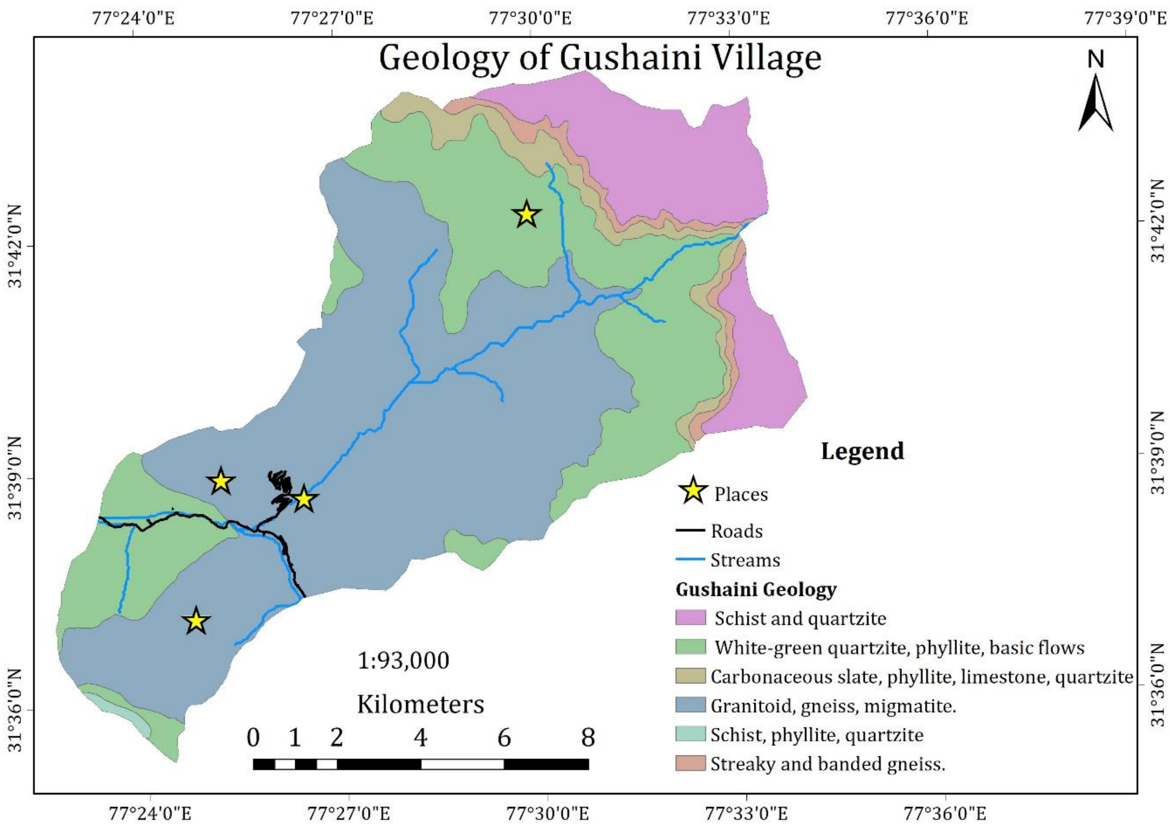
1.3.1 Geology of Sainj Village

The geology of the Sainj village reveals a diverse composition, characterized by the presence of white-green quartzite, phyllite, and basic flows. Notably, extensive portions of the village exhibit a prominent occurrence of Granitoid, gneiss, and migmatite, indicating a high grade of metamorphism in the surrounding region. This suggests significant geological transformation and pressure-induced changes over time. In the northeastern region of the village, there is a predominant lithological composition of phyllite and quartzite, interspersed with some occurrences of basic flows. These formations are further influenced by intrusive basin flows of white-green quartzite, phyllite, and basic flows, indicating complex geological processes in the area. Moreover, a smaller portion between the larger Granitoid formations and the white quartzite and phyllite features schist, phyllite, and quartzite. This interplay of different rock types suggests intricate geological dynamics and the influence of various geological forces over the development of the landscape in Sainj village.



1.3.2 Geology of Gushaini

Gushaini village, situated in the southern part of the Kullu district, unfolds a captivating geological tableau. To the north, the landscape is characterized by schist and quartzite formations, with intermittent intercalations of quartz, suggesting a history of regional metamorphism. As one traverses southward, a thin but significant layer emerges, showcasing carbonaceous slate, phyllite, limestone, and quartzite, providing insights into the complex interplay of sedimentary processes over time. This sedimentary layer is complemented by streaky and banded gneiss, introducing high-grade metamorphic rocks into the geological narrative. In the northern region of Gushaini, a remarkable formation takes centre stage, marked by Granitoid, gneiss, and migmatite. These high-grade metamorphic rocks signify profound geological transformations, with Granitoid indicating intrusive magmatism, gneiss displaying signs of regional metamorphism, and migmatite revealing a history of partial melting and recrystallization.



Chapter-2

Flood

2.1 Data and Analysis

2.1.1. Hydrometeorological Data Sources

The global SMAP L4 soil moisture geophysical data across a 9-km Equal-Area Scalable Earth (EASE) grid were chosen from the wide range of SMAP products that were utilized in this study. SMAP's integrated L-band radiometer and radar equipment were able to obtain global estimates of soil moisture from the top 5 cm of the soil with intermediate resolution (9 km). SMAP L4 mission provides 3-hourly time average estimations of the volumetric soil moisture at the soil's surface (0–5 cm) and in the root zone (0–100 cm). The SMAP L4 product provides infiltration, overland runoff, snow melt, and snow depth. To analyze the changes in the snow depth data, FLDAS NOAH model L4 daily data with 0.01 x 0.01 degree has been used.

From ERA5, hourly precipitation data at 0.25 x 0.25-degree resolution, wind velocity (u, v) component at 10 m resolution, vertical wind velocity component at 500 hPa, and geopotential height at 500 and 750 hPa were used for analysis. To quantify the amount of precipitation during the catastrophic event from the ground, hourly precipitation data was provided by the State Data Center (SDC), Ministry of Jal Shakti, HP. This data has been collected from GPRS (General Packet Radio Services) telemetry cloud-based system, which can be accessed and remotely monitored using Wi-Fi or any other networks. Hourly River Stage values of Victoria bridge (Latitude: 31°42'41"N and Longitude:76° 56' 01"E) located in Mandi district were also provided by SDC.

2.2 Analysis and key insights

2.2.1 Meteorological context

Observed Rainfall Patterns

The intricate weather patterns in the Himalayas resulted in an unprecedented and catastrophic volume of rainfall in HP during the second and third weeks of July 2023. Observation gauges indicate that the rainfall event began during the afternoon hours on 8th July. Data from a total of 17 stations have been found to be effective for the two districts, i.e., Kullu and Mandi, for understanding the rainfall pattern. For four consecutive days from 8th July to 11th July 2023, the daily rainfall data of these stations has been shown in Figure 3. It is reported that multiple heavy rainfall spells during July 08–11 resulted in severe flooding over Mandi and Kullu Districts. Twelve of the analyzed stations recorded more than 30 mm of rainfall on the same day (8th July). Barot and Sarkaghat stations of Mandi received very-high rainfall maximum of 56.5 mm and 58 mm, respectively. Kullu gauging station observed a maximum daily rainfall of 45 mm on 8th July.

These rainfalls on 8th of July triggered floods in Kullu and Mandi districts. On 9th July, 11 stations were found to have recorded very high rainfall of more than 100 mm over these two districts causing catastrophic flooding in these districts.

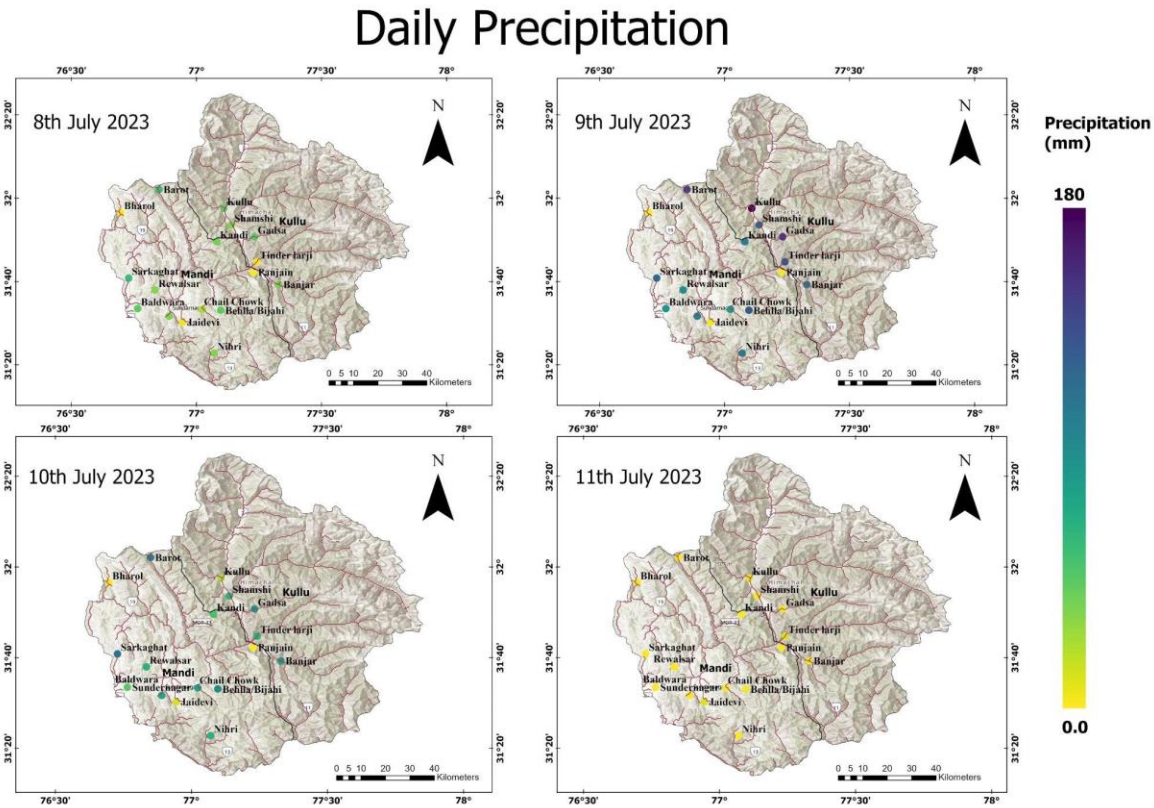


Fig. 3. Daily precipitation data of 17 stations in Kullu and Mandi districts

As it can be observed from Figure 3, stations located in Kullu observed a record high value of 180 mm on 9th July. On the same day, the Gadsa station of Kullu alone received 150.5 mm of rainfall. Barot and Bhella stations received very high rainfall of 144.5 mm and 131.5 mm on the same day in the Mandi district, respectively. There has been persistent rainfall in a few stations of Mandi on 10th July, i.e., Sarkaghat, Barot, and Bella received heavy rainfall of 110 mm, 102.5, and 95.5 mm, respectively. Gadsa and Banjar stations received 87.5 mm and 80 mm in Kullu District on the same day (10th July). High rainfall values have been shifted from Kullu to Mandi district from 9th July to 10th July. After these heavy rainfall events, on 11th July normal rainfall has been observed in these two districts. At most of the locations, the rain amounts, therefore, exceeded the typical monthly precipitation for July. Maximum hourly values and their timing can also be observed in Figure 4. The Sarkaghat station in Mandi District observed a maximum hourly rainfall intensity of 22 mm on 10th July 2023 at 11 am. Followed by Tinder largi station in Kullu District with maximum hourly rainfall intensity of 18 mm on 9th July 2023 at 2 pm. Barot station recorded 17 mm and Kullu station recorded 16 mm on 10th July 10 am and 9th July 9 am respectively.

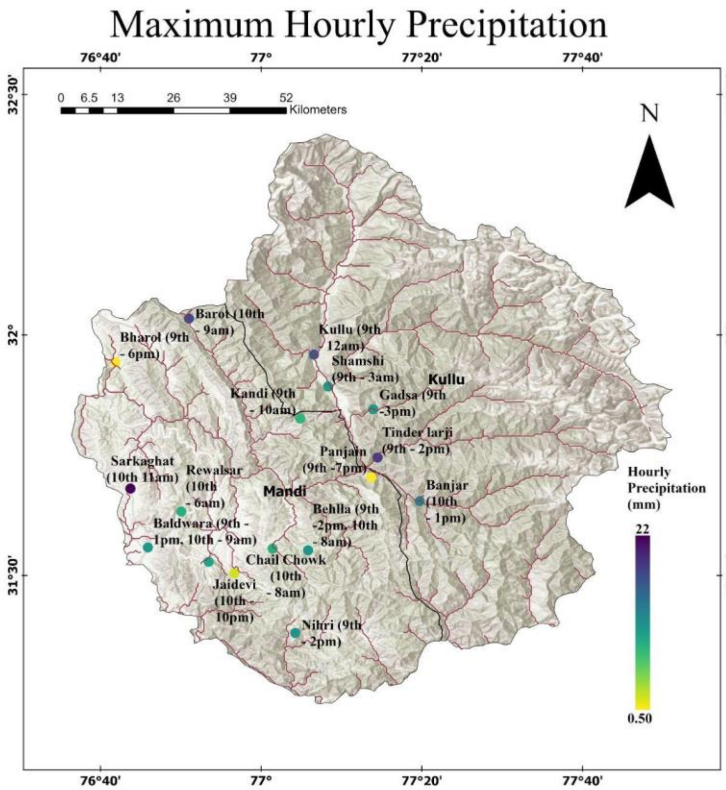


Fig. 4. Maximum hourly precipitation of 17 stations in Kullu and Mandi districts

Insights from reanalysis data

The diurnal wind patterns at the 700 hPa level (Figure 5) indicate the formation of strong convergence zones leading to heavy localized precipitation over HP. While negative vertical velocity values indicate the ascendant movement of winds (Tamarin-Brodsky & Hadas., 2019), leading to the creation of strong upwelling zones that foster an environment conducive to continuous and intense precipitation. This phenomenon was particularly evident on July 8 and July 9 (Figure 6), resulting in exceptionally heavy rainfall across HP. The ERA5 reanalysis data distinctly indicated robust upward movement of winds over the region, resulting in the highest daily accumulated rainfall on July 9th. This observation concurred with the actual data findings.

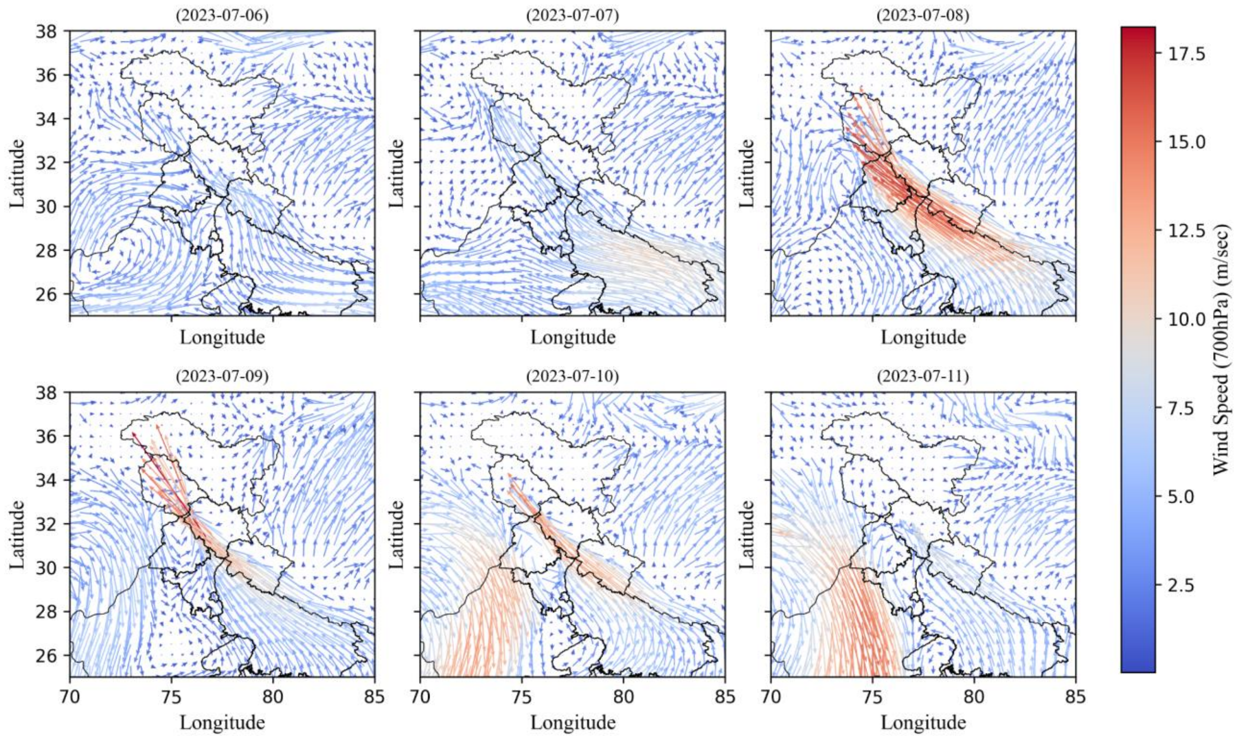


Fig. 5. Diurnal Wind profiles at 700 hPa for July 6-11, 2023 obtained from ERA5 Reanalysis

Profiles of vertical velocity employ a pressure-based vertical coordinate system. As pressure declines with altitude, the presence of negative values indicates notable upward movement elucidating the gathering of wind convergence laden with moisture at lower altitudes (Tamarin-Brodsky & Hadas., 2019), resulting in brief but heavy cloud precipitation that subsequently triggers intense flooding.

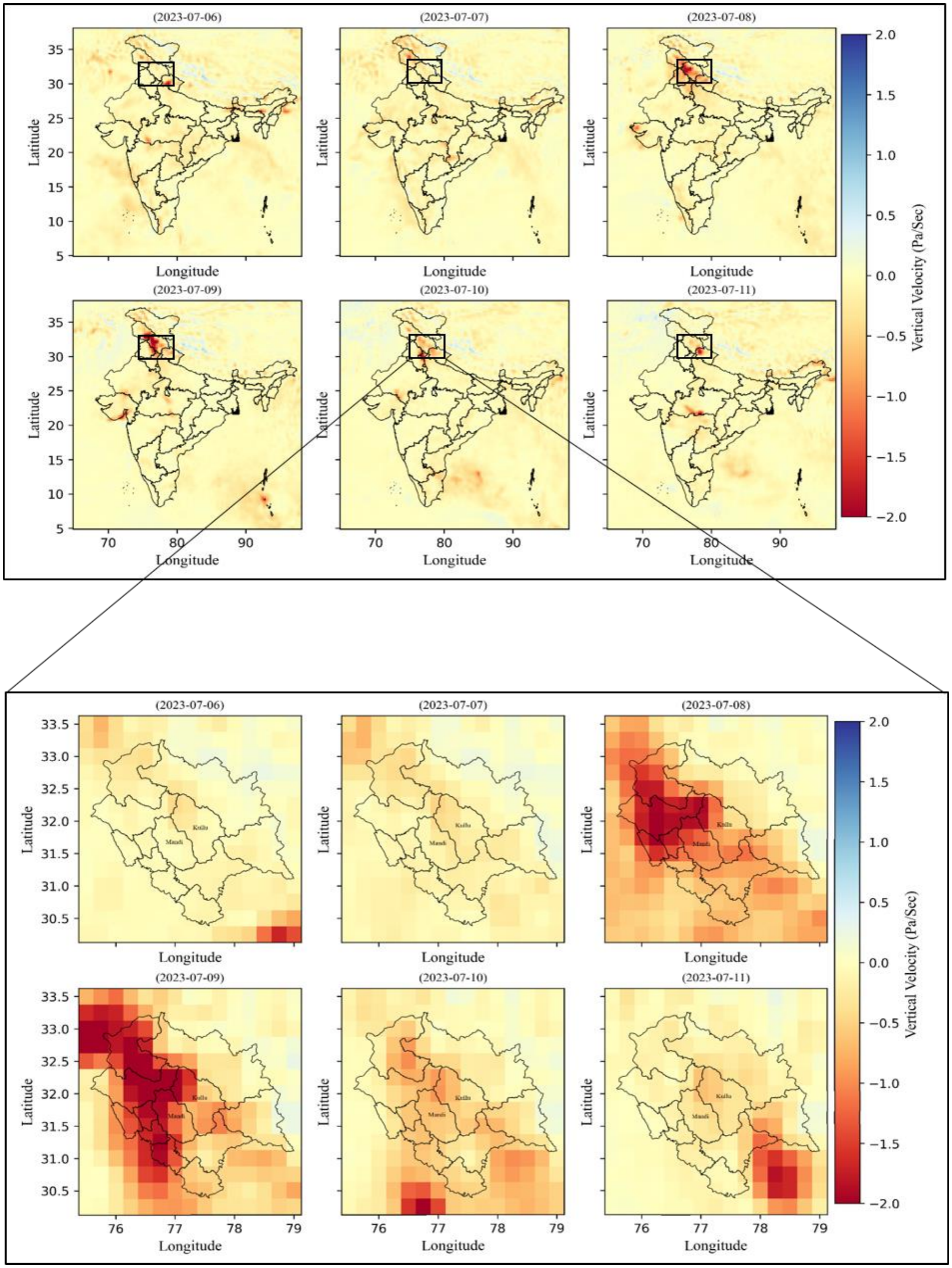


Fig. 6. Climatological vertical wind velocity profiles at 500 hPa: July 6-11, 2023 (ERA5 Reanalysis)

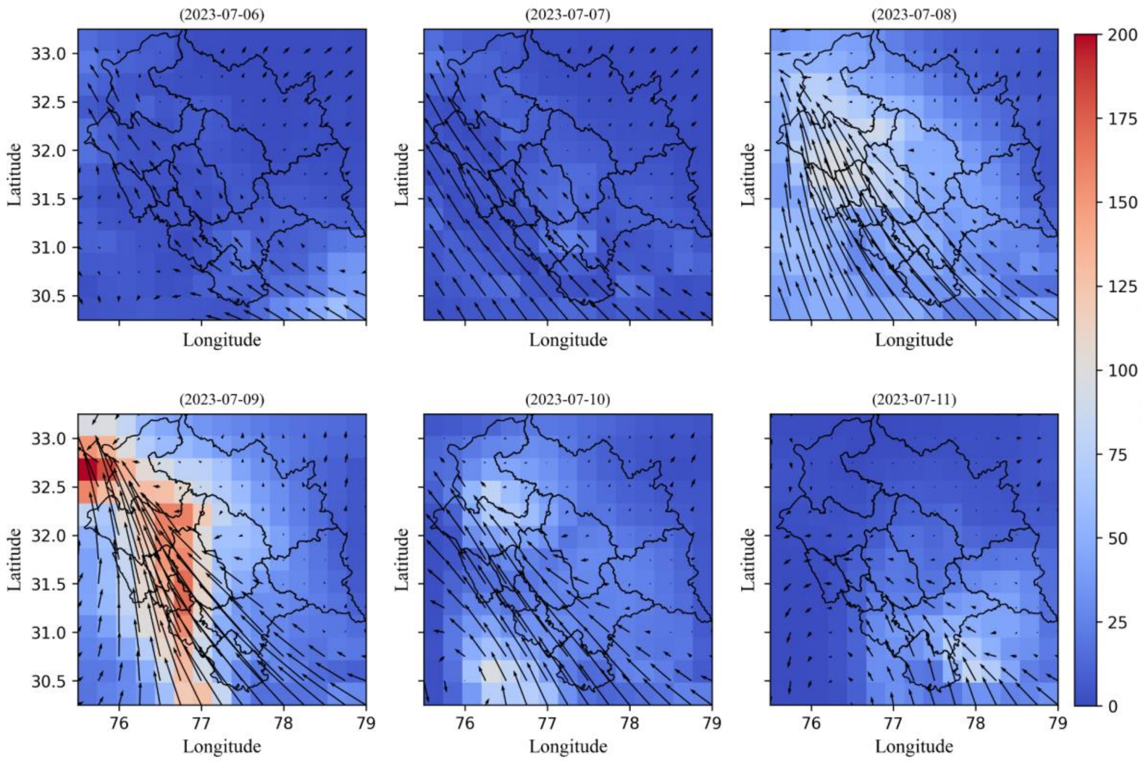


Fig. 7. Daily accumulated rainfall and wind velocity profiles at 700 hPa for July 6-11, 2023

The presented data (Figure 7) showcases the interaction between wind dynamics at 700 hPa and the accumulated daily rainfall. This representation effectively elucidates the manner in which wind dynamics exert control over the spatial distribution of rainfall over the region. Notably, a distinct pattern of strong wind convergence becomes evident in the Mandi and Kullu districts on July 8th and 9th. This observed convergence aligns coherently with the heightened levels of accumulated rainfall and resulting flood conditions in these districts. Although wind drift is considered a significant influencer on rainfall-runoff characteristics in a region. In our case, wind dynamics and localized extreme rainfall relationship validate wind-driven convergence as a catalyst for such weather events.

2.3 Hydrological Perspective

2.3.1. Role of Antecedent Soil Moisture

Antecedent moisture content plays an important role in intensifying a flood event. In a study done at the Godavari River Basin, India it was found that more than 80% of the floods that had occurred due to extreme precipitation occurred when the antecedent moisture was high (Garg & Mishra, 2019). Due to heavy rains on 7th and 8th of July, the soil moisture reached its peak values near saturation in Kullu and Mandi districts as shown in Figure 8.

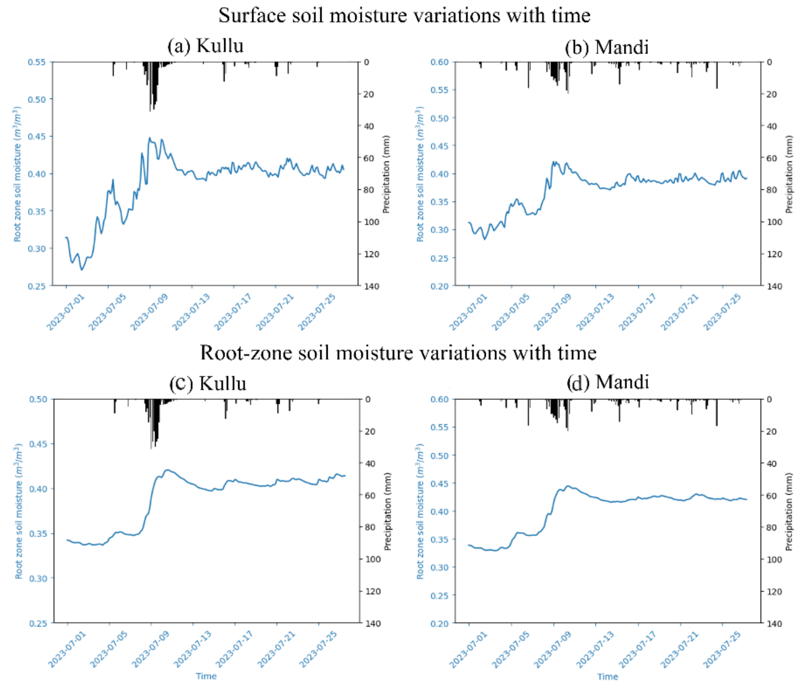


Fig. 8. Change in surface and root zone soil moisture in Kullu and Mandi district.

An increase in the soil moisture content resulted in a reduction in the infiltration rate throughout the region (Figure 8). As it can be observed from Figure 9 the infiltration rate which had a peak value of 12.63 mm and 15.44 mm for Kullu and Mandi Districts on 8 July at 07:30 PM which then decreased rapidly even when there was an increase in precipitation. Coupled with intense rainfall, this decrease in infiltration rate contributed to a significant increase in infiltration-excess overland flows, exacerbating the severity of floods. Due to this coupling, overland flow hit its peak on the 9th of July as shown in Figure 9.

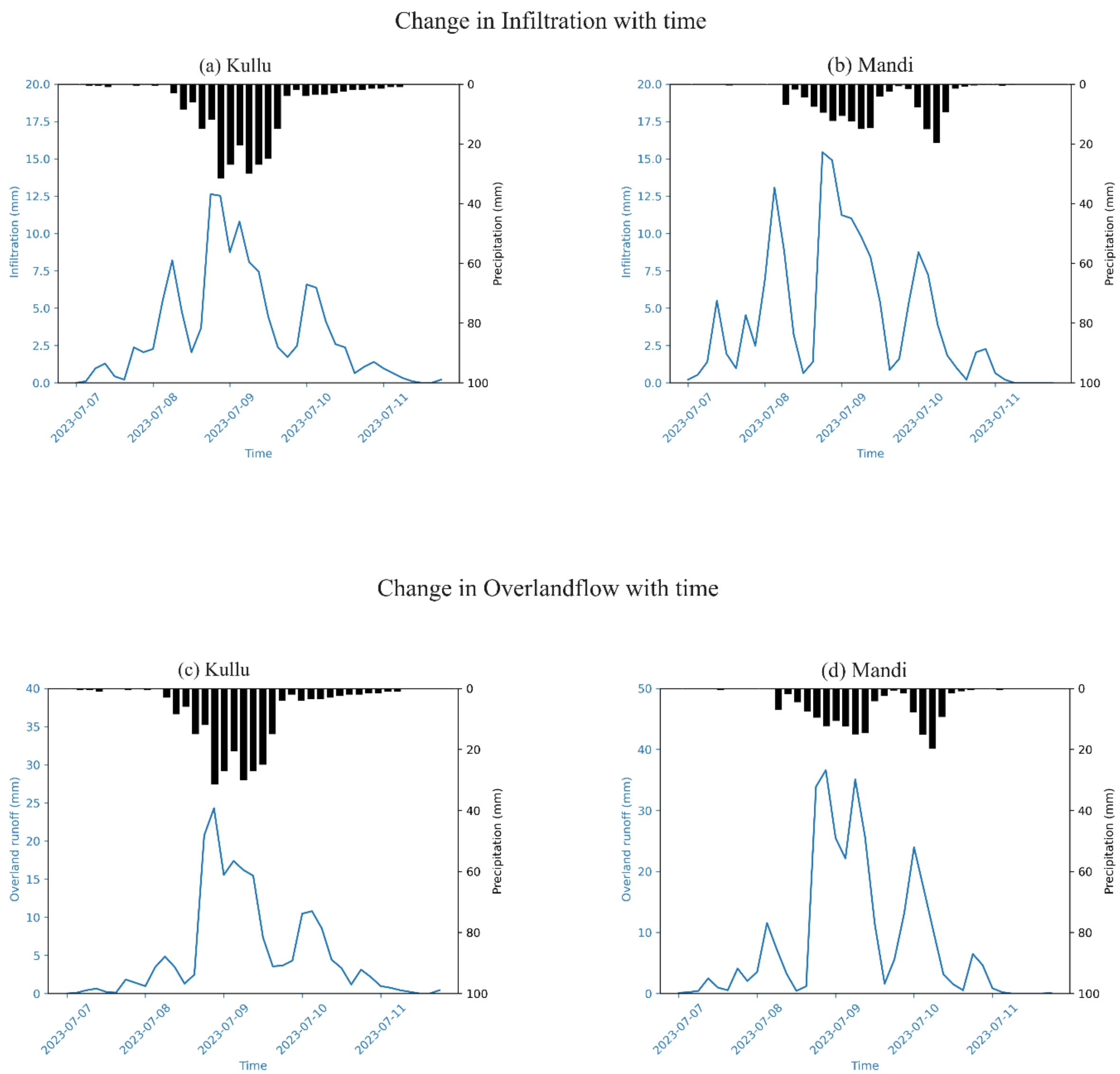


Fig. 9. Change in infiltration and Overland runoff at Kullu and Mandi district. Ticks on the x-axis represent 12:00 AM for the mentioned date. The values on the y-axis show the total cumulative value in 3-hour intervals.

This decrease in the rate of infiltration is due to an increase in flow resistance caused by the increase in the length of flow channels within soil (Garg & Mishra, 2019). Other causes may include swelling of soil particles due to the absorption of water and clogging of soil pores by particles carried down from above by the infiltrating rain. For smaller rainfall events, Grillakis et al. (2016) have also found the flood peak to have a sensitivity of more than 3 percent for a 1 percent change in soil moisture (Grillakis et al., 2016). Also, both big and small catchments have been found to have a high correlation between antecedent soil moisture and peak flood flow (Wasko & Nathan, 2019).

As the peak rainfall happened on 9th July, it is interesting to note that the soil moisture continued to have very high moisture content near saturation due to soil drainage characteristics and minor precipitation events. However, this increased soil moisture increases the risk of inflating the flood risk for any heavy rainfall event. It is interesting to note that the primary cause of major floods is generally saturation-driven overland flow. This occurs when the soil reaches a state of saturation thus preventing any further infiltration of water, causing it to flow across the surface (Grillakis et al., 2016).

2.3.2 Role of Rain-on-snow and Snow Melt

Snowfall at higher altitudes started to accumulate on 7th to 9th of July as can be noticed from Figure 10.

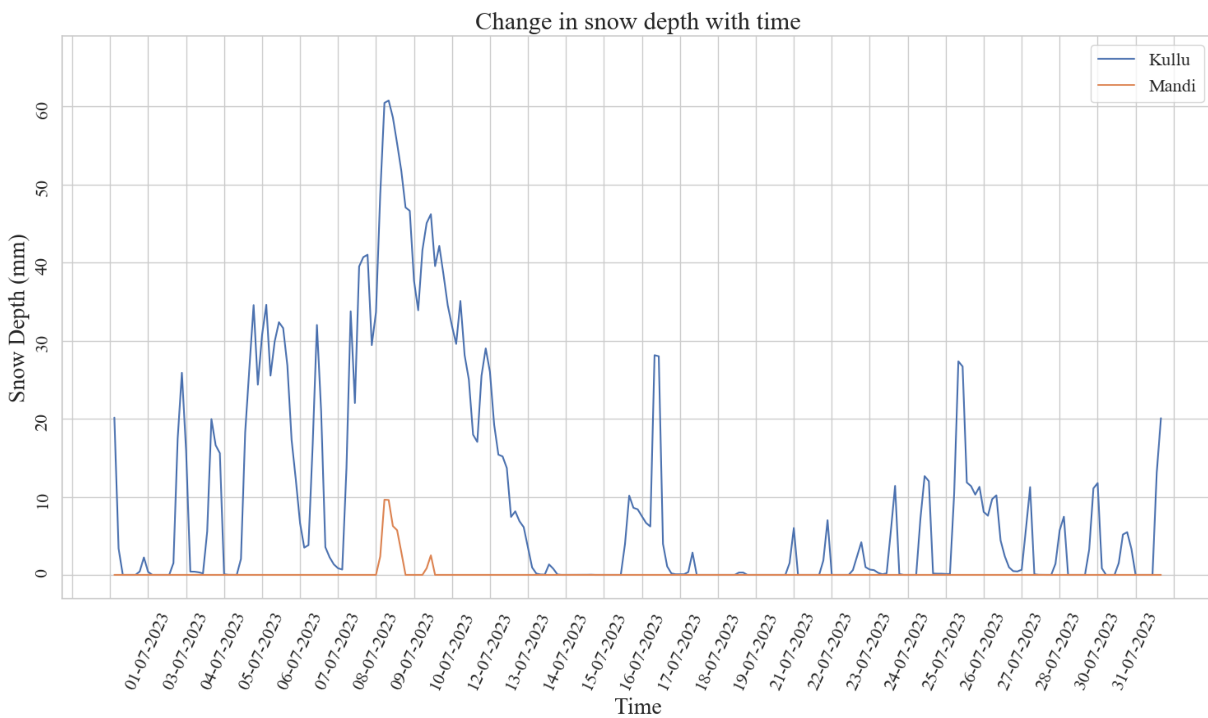


Fig. 10. Change in snow depth in Kullu and Mandi districts

Higher reaches of Kullu district received a good amount of snowfall and snow depth peaked on the 08th of July at 10:30 PM. However, as rain fell on these snow-covered areas, there was a rapid increase in the snow melt rate (Figure 10) deteriorating the flooding situation further in the Beas River basin.

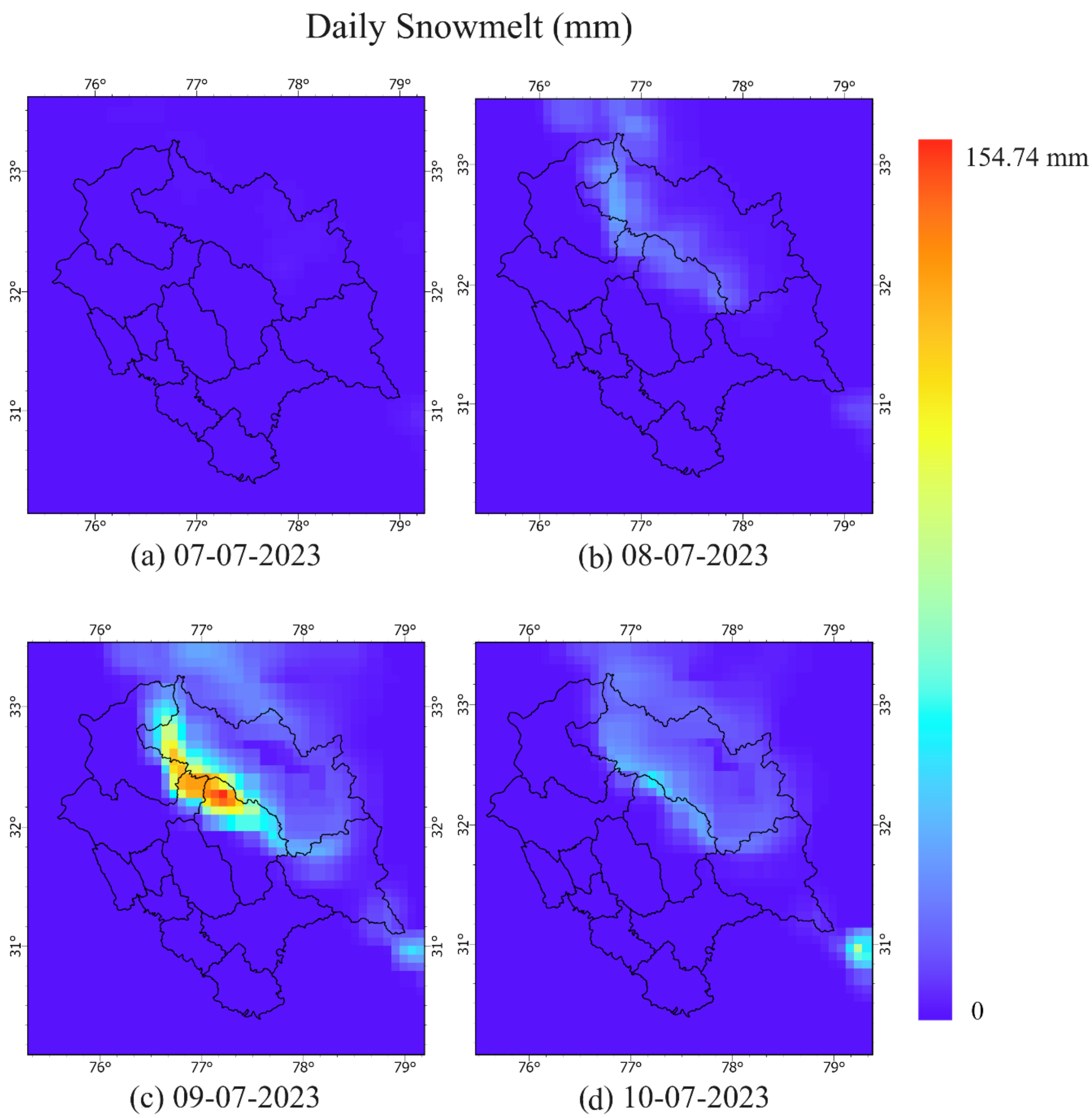


Fig. 11. Spatial Distribution of snowmelt in HP

Rain typically is at a higher temperature than snow and also has a higher heat capacity, leading to more efficient melting. Snow continued to melt for the next six to seven days which helped in sustaining the flow in the main river channel. Rain-on-snow (ROS) floods have been known to cause economic damage as well as the endangerment of human lives due to their combined effect of rainfall and snowmelt (Sezen et al., 2020).

Kumar et al. (2007) have also shown that the runoff from melting snow and glaciers makes up approximately 35% of the yearly discharge of the Beas River at the Pandoh Dam (Kumar et al., 2007). The intricate interplay between rain events and existing snowpack amplifies flood risks, necessitating precise monitoring and predictive models. Addressing this specific aspect of floods is paramount for enhancing our preparedness and response strategies and minimizing damage to infrastructure and communities. As we continue to grapple with the complexities of changing climate patterns, further investigation into rain-on-snow interactions will undoubtedly contribute to more effective flood management and a more resilient future.

Before the occurrence of the heavy flood, the stage value at Victoria Bridge was around 6.25 m across the Beas River (Figure 11). The anomaly in stage has been observed from 8th July 7 pm onwards where stage discharge exceeds 7 m for the first time during the flooding event. The peak stage was observed on 9th July 2023 at 6 p.m. with a maximum value of 16.01 m. Since this station is located downstream of the Pandoh dam, it is important to note that this stage is being generated from managed discharge. So as the dam was filling fast on 08-July, the water was released from the dam to have more capacity to absorb the next flood wave. Further, as a large amount of flow reached the dam on 09-July, we can see another peak on the same day which means the dam could not accommodate more water.

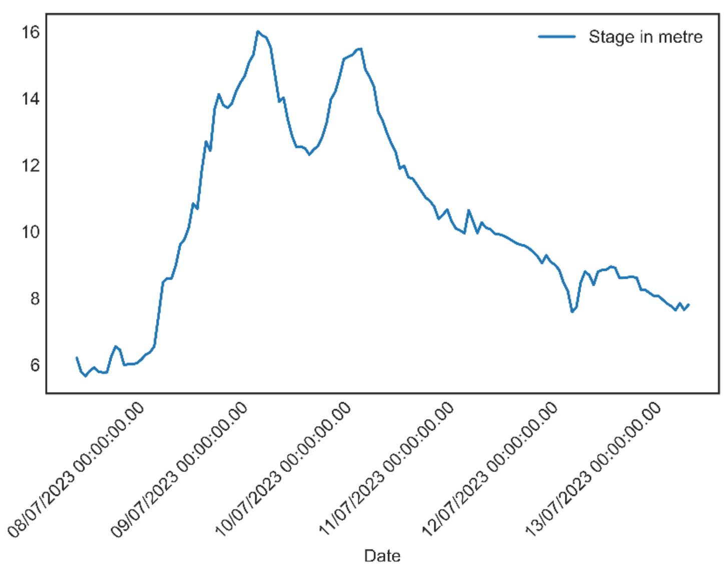


Fig. 12. Stage value of Victoria Bridge in Mandi District

2.4 Assessment of Flood Damage

The flash flooding caused by heavy rainfall led to severe infrastructure damage across multiple locations in the Kullu District. Bridges were either partially or fully damaged, with some being completely washed away by the high-intensity floodwaters. For instance, the bridge at Neuli was entirely swept away, cutting off connectivity and access between 4-5 panchayats in the area. The residents have constructed a makeshift wooden plank bridge as an interim solution to facilitate movement across the river. Similarly, the floodwaters weakened and displaced the bridge at Tareda Bekar. The bridges are crucial links for the villages, and their destruction has hampered mobility and relief efforts.

Houses, shops, and other buildings situated precariously along the riverbanks also suffered extensive damage or were fully swept away due to the sudden rise in water levels and erosion of banks. In Sainj Market, approximately 30-35 houses and shops were submerged or destroyed as the floodwaters inundated the area. The buildings were unable to withstand the impact of flooding as they were constructed without accounting for adequate buffer space from the river. At Bakshal village, 2-3 houses along the riverbanks have been washed away. In Tareda village, a few homes positioned on the edges of the river (in the flood plain) were carried away by the turbulent floodwaters. The proximity of the settlements to the river made them extremely vulnerable.

The flash floods also caused damage to road infrastructure and retaining walls at multiple sites. At the Spangani village situated uphill, roadways have developed cracks and subsided substantially. The retaining walls too have collapsed, indicating their inability to withstand the flood intensity. Near under construction Sainj Degree College site, road infrastructure suffered erosion across a 45m stretch as outer retaining walls failed. At Bihali village, the paved road constructed along the riverbank has been entirely washed away due to the loss of retaining walls intended to protect the infrastructure. Cracks have emerged on roads in other areas as well. The retaining walls and roads were inadequately designed and constructed to prevent damage during severe flooding events.

In addition to the flooding, the heavy downpour triggered numerous landslides across the valley which aggravated the infrastructural damage. The landslides occurred on steep hill slopes which became destabilized due to soil saturation, absence of stabilizing vegetation, and seepage pressure. Tension cracks, soil subsidence, and toe erosion were visible indicators of decreased slope stability. At Khanidhar village, a major landslide event destroyed apple and cedar trees on the hillside. Likewise, orchards and retaining walls above the road at Sainj Market were destroyed in a landslide spanning 45m. The downward movement of landslide material also impacted bridges, roads, and buildings situated downhill. For instance, the landslide near Neuli village completely blocked road connectivity. At Kartoh village, approximately 4-5 houses at the hill's base were buried due to a landslide higher up. The haphazard hillside development and lack of stabilizing measures made the region more prone to landslide disasters during heavy rainfall.

One of the main underlying factors exacerbating the flood damage was encroachment along the riverbanks which reduced the natural floodplain area. Building settlements, markets, and infrastructure too close to the river left no room for the water to spread out, increasing the flood magnitude. For instance, at Sainj Market, shops and houses were constructed along the river with no significant riparian buffer space. The river's natural meandering pattern was also disrupted due to human interventions like embankments and barrages. Altering the river's course led to imbalances in sediment load and erosion patterns, resulting in damage to nearby infrastructure. Near Spangani village, a change in the river's alignment is believed to have caused erosion of farmlands and settlements. The absence of adequately engineered protection measures along realigned sections also contributed to the damage.

Inappropriate land use practices such as deforestation and unregulated construction on steep hillsides further exacerbated the flood impact. Removing vegetation cover on slopes surrounding settlements like Kartoh and Khanidhar reduced soil stability and water absorption capacity. This led to rapid surface runoff and an increased risk of landslides. The siting of infrastructure and agricultural activities along inherently unstable slopes was unsafe. The apple orchards and retaining walls were severely impacted near Sainj Market on a landslide-prone slope: uncontrolled hillside development and lack of stabilizing measures led to such hazardous conditions.

The lack of emergency preparedness and early warning systems also contributed significantly to the devastation caused by the flooding. The absence of automated flood gauges and meteorological stations providing real-time data prevented authorities from issuing accurate alerts early on. As a result, the communities were caught off-guard when the floodwaters rapidly inundated settlements situated close to the rivers.

Anthropogenic factors like improper waste disposal created secondary hazards that amplified the damage. At Jiwa and Sharan villages, construction waste material carelessly dumped along the riverbanks without providing proper slope stability measures by a hydropower company was washed downstream by the floods, destroying the properties of the neighbouring village. Such irresponsible waste disposal along rivers is an unsafe practice. It indicates a lack of environmental monitoring and regulation for construction projects.

The findings highlight that historical climate and precipitation data used to design infrastructure like bridges, roads, and retaining walls proved insufficient, given the current realities of climate change. The magnitude of the recent rainfall and flooding event exceeded the normal thresholds these structures were built to withstand. There is an urgent need to incorporate future climate projections and updated extreme weather event data into engineering designs to make infrastructure more resilient against climate change impacts.

The damage was also amplified due to the cumulative effect of multiple compounding factors. For instance, at Spangani village - the subsidence of roads occurred not only due to floods washing away retaining walls.,I but also because the village is situated on an unstable slope. Similarly, at

Neuli village - the bridge destruction resulted from both the landslide material debris and the flash flood currents. A single extreme event led to cascading failures due to existing vulnerabilities across the natural and built environment.

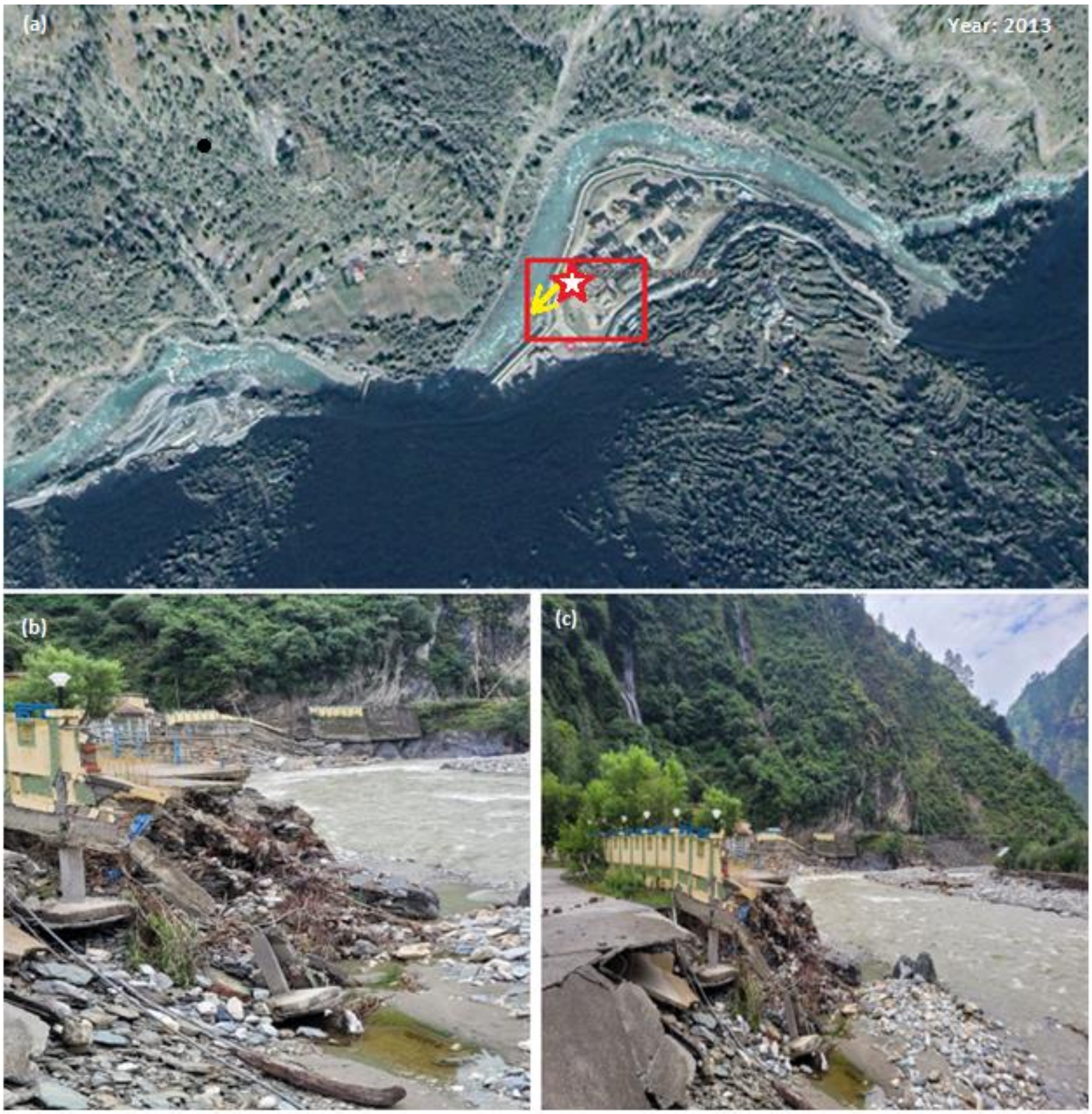


Fig. 13: Extensive damage to road infrastructure and collapse of retaining walls near NHPC residence at Spangani village caused by severe flash flooding. Major landslide visible on the opposite riverbank covering a span of around 100 meters.

Fig. 14. The main vehicular bridge providing connectivity at Tareda village has been completely washed away by the high-intensity flash flood event. Additionally, 2-3 houses situated precariously along the edges of the river were also swept away.

Fig. 15. The flash floods coupled with the erosion of banks due to changes in the river's natural meandering pattern led to the complete destruction of farmland spanning over 300 acres and the loss of 3 houses at Bakshal village.

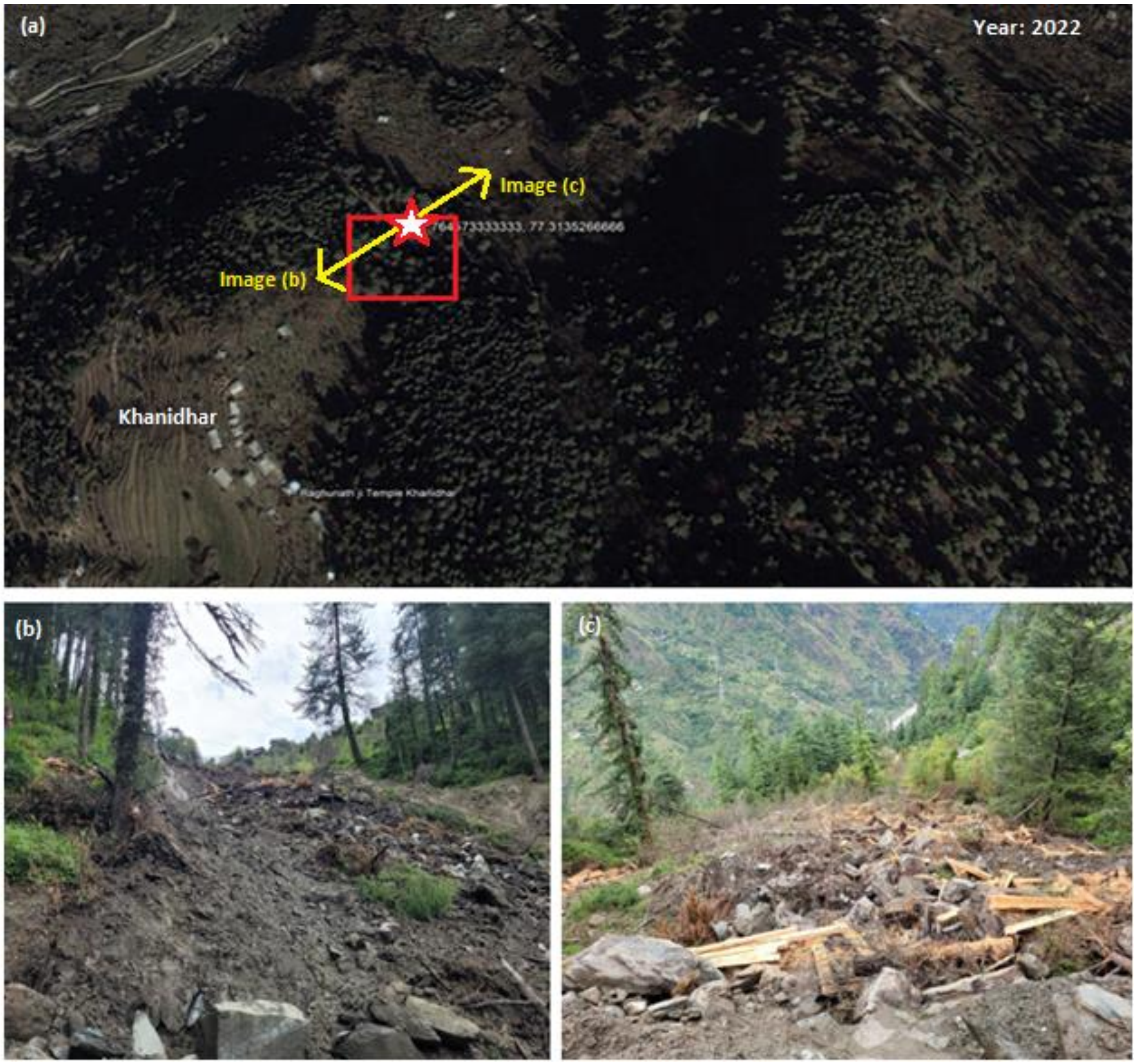


Fig. 16. A major landslide spanning approximately 200 meters wide has occurred at Khanidhar village, leading to destruction of several old growth deodar and apple orchards on the hillside.

Fig. 17. Near Sainj Market, a landslide caused subsidence of ground by around 1.5 meters over a 50 meter area, resulting in displacement of the retaining wall intended to provide slope stability. The root zone stability of the orchards has been impacted.

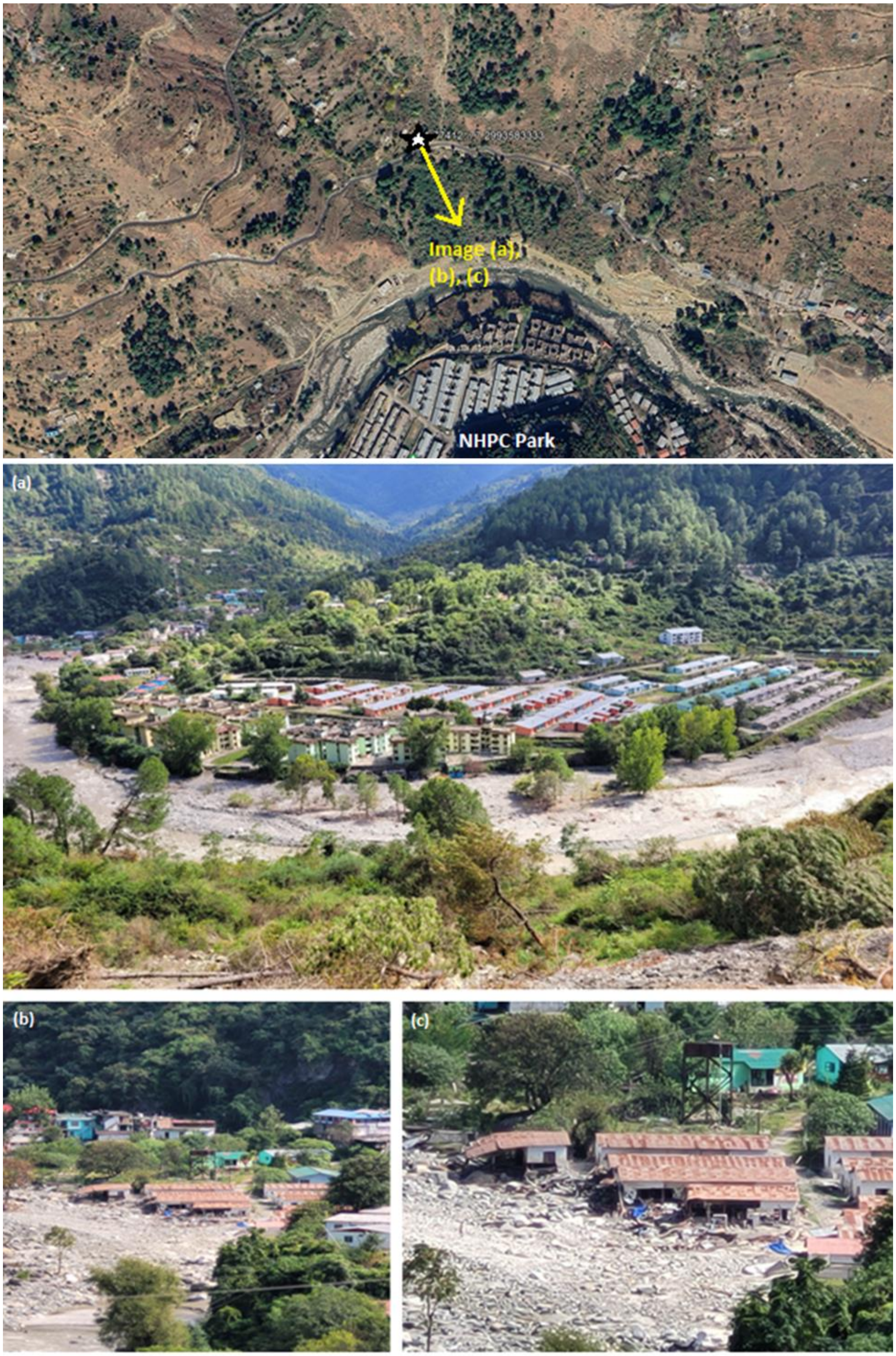


Fig. 18. At Sainj Machina Nala, several houses were completely destroyed and access roads were blocked due to damage by flash floods and a landslide caused by instability of the hill slope base.

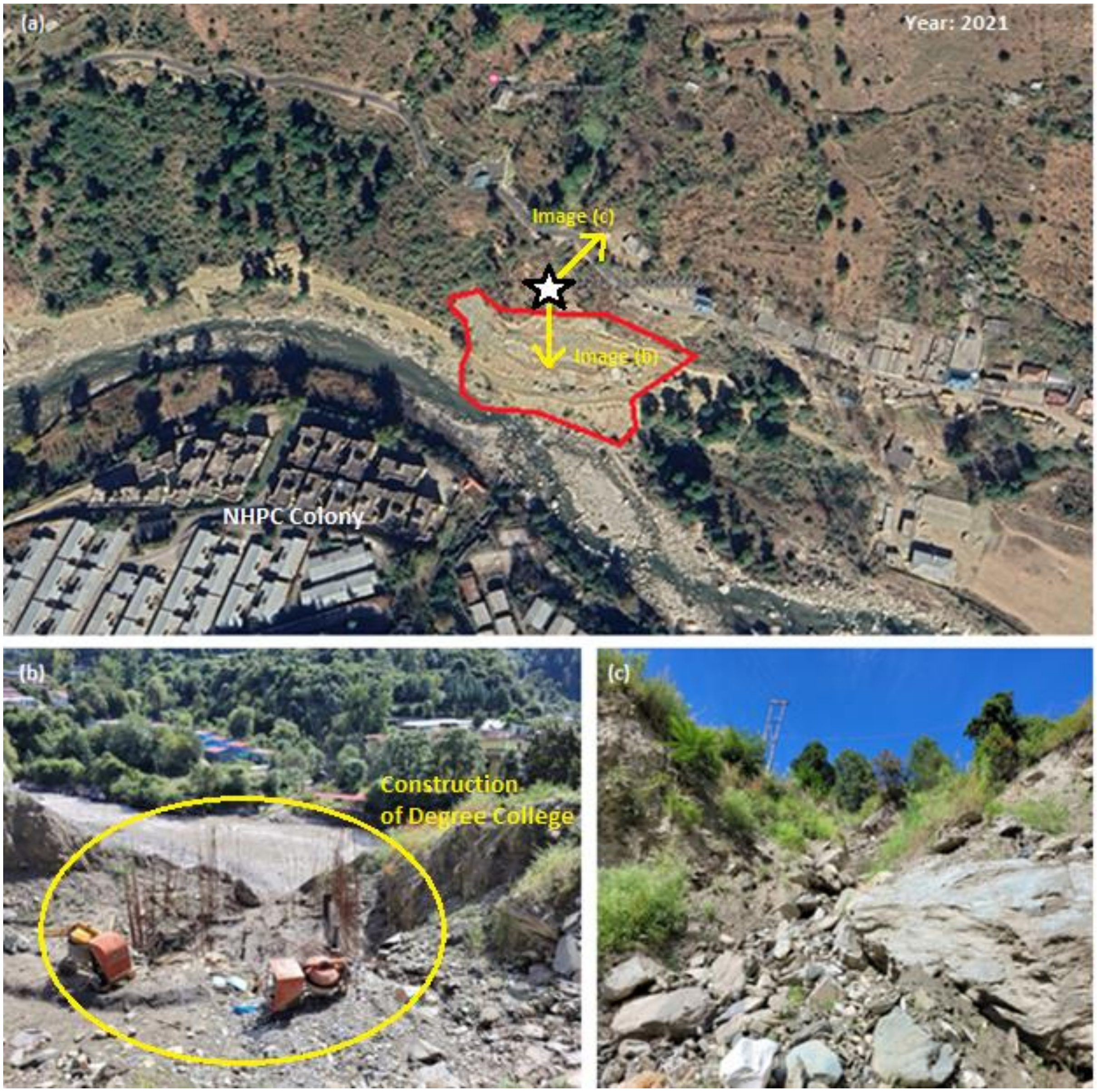


Fig. 19. Near the site for proposed Sainj Degree College, a 45-meter length of the road has been washed away. An adjacent landslide above the road led to collapse of retaining walls intended to provide slope stability.

Fig. 20. In Kartoh village, approximately 5 houses constructed at the base of a hill were completely buried under debris due to a major landslide spanning over 150 meters wide. Tension cracks were visible on the slope.

Fig. 21. A massive landslide extending over 40 meters vertically has occurred at Neuli village, fully destroying a connectivity bridge. The landslide has blocked access across 4-5 panchayats, requiring a makeshift crossing.

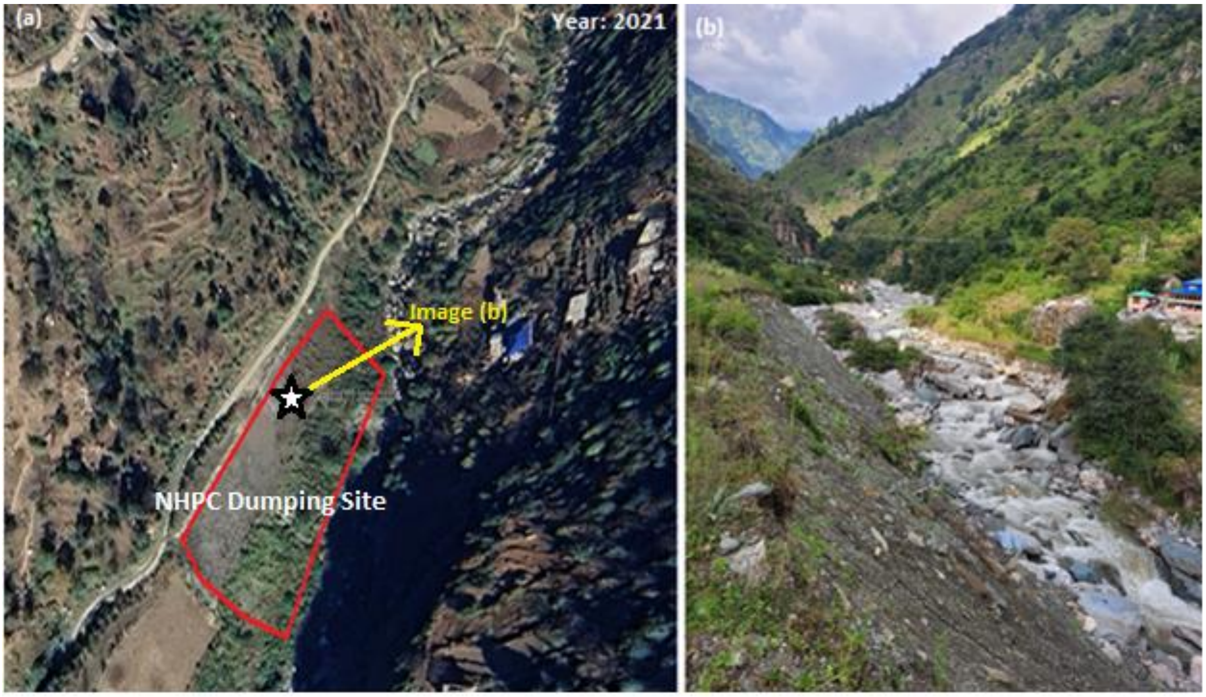


Fig 22. At Jiwa & Sharan villages, improper waste disposal along the riverbanks by NHPC got washed downstream during the floods, causing damage to properties of the neighboring village.

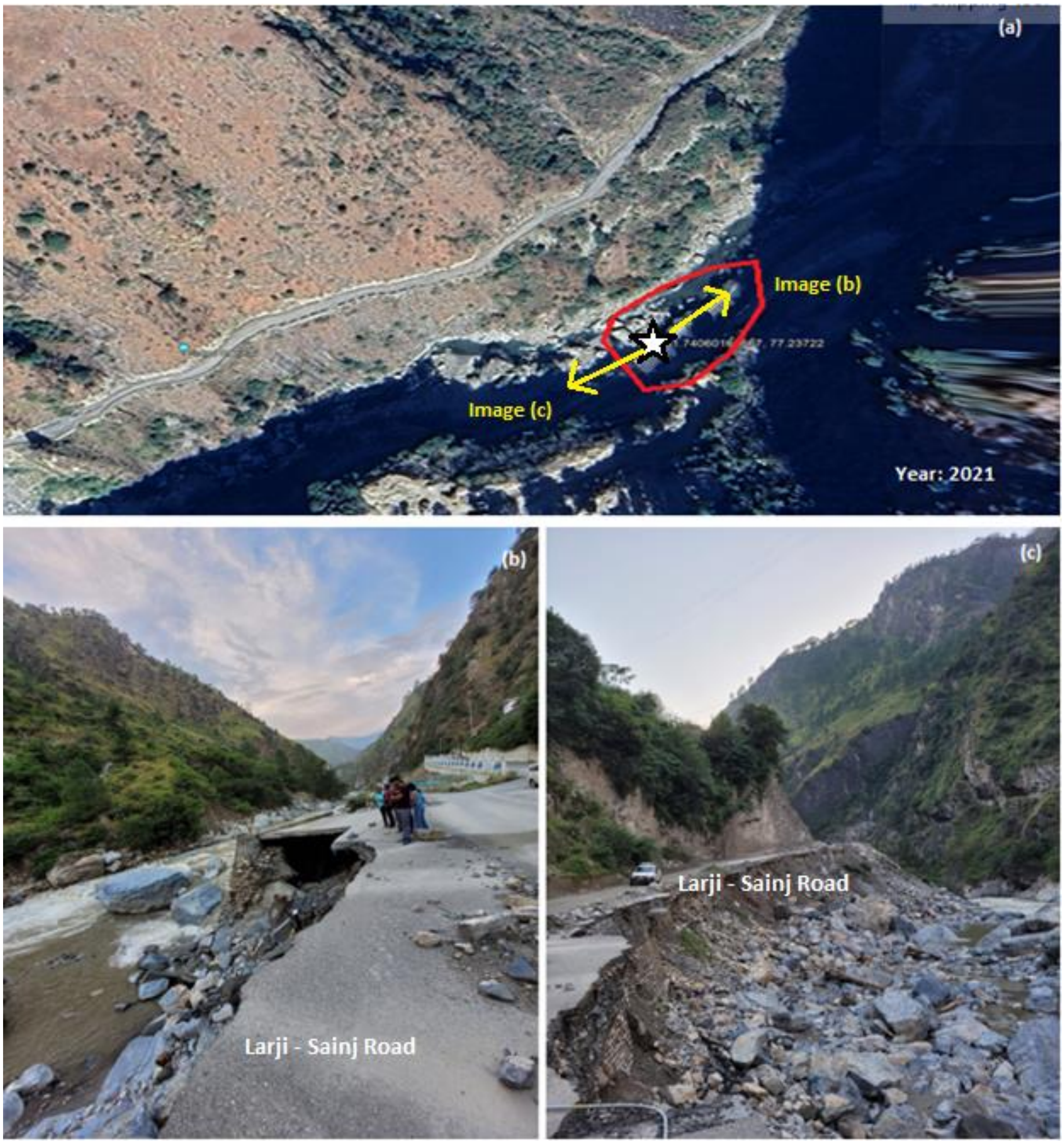


Fig. 23. In Bihali village, the paved road stretching approximately 300 meters constructed along the riverbank has been completely washed away due to flash floods eroding away the banks.

2.5 Damage to Water Supply Infrastructure

The devastating floods in Himachal Pradesh have caused widespread damage to Kullu district's water supply system. Kullu's water supply infrastructure, covering various towns and villages across the district, has borne the brunt of the flood's destructive impact. According to assessments, around 36 of the total 246 water pumps in Kullu have been completely damaged by the surging floodwaters. This alarming scale of damage has led to major disruptions in the water supply to thousands of residents. Additionally, 4 out of 25 vital pump houses have also endured damage, further impairing the water distribution mechanism.

The flood has also inflicted harm on Kullu's water storage infrastructure. Around 96 storage tanks, which play a pivotal role in ensuring consistent water supply in the hilly district, have suffered damage. The cumulative impact has made it challenging for the authorities to maintain regular water supply amidst the destruction. Apart from storage tanks, around 196 intake facilities used to collect water from sources like rivers and streams have met the same unfortunate fate in the floods. With vital water sources being contaminated due to the floods, the task of restoring normalcy in water supply has been further complicated.

The far-reaching damage significantly disrupted the availability of clean and potable piped water supply across several villages and towns in Kullu. Thousands of people have been directly impacted by the effects on the water supply network. Restoration initiatives are underway, but a complete revival is anticipated to be a prolonged process, taking weeks or possibly even months. However, the capacity to meet the demands through currently available limited means remains restricted. With the winter season approaching, time is of the essence as temporary water sources risk being depleted, threatening to aggravate the district's water woes.

This underscores the urgent need for mobilizing resources, manpower and funds to revive Kullu's extensively damaged water infrastructure. Taking stock of the grievous harm inflicted on the water supply network across towns and villages, the road to recovery is set to be a long and challenging one for the district administration. But with the wellbeing and health security of thousands at stake, restoring Kullu's water supply remains an indispensable priority in the post-flood scenario.

Table 1. Extent of damage to water supply components

Component	**Total Numbers**	**Damaged**
Pump	246	36
Pump House	25	4
Storage Tank	1,738	96
Intake Facility	483	196
Water Treatment Plant	31	3
Closed Well with Hand Pump	625	110
Closed well with storage & Electric water pump & Tap stand	94	18

2.6 Role of Dam Management

The question of whether dams exacerbated or alleviated flooding during the Himachal Pradesh disaster has multiple perspectives. In theory, prudent dam operations can moderate floods by storing excess water and regulating downstream flows. However, some news reports reveal violations of dam safety norms by 21 out of 23 hydropower projects, calling into question if they aggravated floods.

The violations include failure to install early warning systems and mechanisms to alert populations before release of water from dams. Reports suggest that sudden upstream water releases from dams like Pong, Pandoh and Malana led to inundation of low-lying areas in Himachal Pradesh and Punjab. This implies faulty dam operations perhaps amplified flood damage. Particularly, government projects like Larji have come under the scanner after past tragic incidents involving loss of lives due to abrupt dam water releases.

However, it is difficult to make a definitive assessment without comprehensive data. While the early reports blame to negligence on part of dam authorities, extreme rainfall could have also overwhelmed flood moderation capacities. Sedimentation concerns can reduce storage spaces while location and coordination of projects play a role too. Without subject matter expert analysis of variables like discharges, coordination, sedimentation and rainfall data for each dam, concluding whether dams exacerbated or alleviated floods seems premature.

While the violations expose dam operational latencies that potentially aggravated floods, extreme weather can diminish flood mitigation capacities too. Dedicated technical investigation assessing each dam on variables that influence flood moderation would be required for an authoritative evaluation.

Chapter-3

Geotechnical Assessment of Damage

3.1 General

This report covers the geotechnical assessment of the extensive damage caused by unprecedented monsoon rains in Kullu district, Himachal Pradesh. The assessment was conducted during a site visit on 16-09-2023 and 17-09-2023 to evaluate the impact of slope instability (landslides, debris flows, toe erosion, subsidence, etc.) on infrastructure, including houses, shops, bridges, and roads. The purpose of this report is to document the extent of the damage and provide suitable recommendations. The findings highlight the urgency of addressing the immediate needs and implementing long-term solutions to prevent future damage.

3.2 Information received

The unprecedented torrential rainfall and cloud bursts experienced by the state in this monsoon season, especially in July and August 2023, have caused severe landslides and settlements in Kullu district. It has been observed that the various regions in the Kullu district are experiencing a slow rotational failure and toe erosion, which is causing settlement in many areas down the hill. As a result, buildings above and below the road were completely or partially damaged. It has also been observed that the subsidence in the affected areas is still ongoing. Many buildings standing above the roadside that have developed cracks pose a significant threat to commuters and, therefore, need to be dismantled. During our site visit, we also had many insightful conversations with locals where they expressed their concerns and anguish.

3.3 Observations

The following observations are made from the rapid visual-based screening:

1. Around 7 houses in the area were completely or partially damaged. A house above the roadside made of wood and stone, which was around 90 years old, was completely damaged due to the settlement in the region (Fig.24). Buildings have tilted in the sliding zone of around 100 meters and have developed huge cracks in the walls (Fig. 25).

Fig. 24. Damaged house made of wood and stone.

Fig. 15. Tilted house with large cracks.

2. At another location, the road was shifted around 2 to 3 meters due to subsidence that resulted from the continuous rainfall in July 2023. Fig. 26 shows a pole aligned before subsidence and now shifted downwards and sideways. Further, the damaged road has been temporarily repaired using locally available material.

Fig. **26.** Shifted pole due to subsidence.

Fig. 27. Damaged Road filled with local material.

3. Slow progressive damage was observed in Bandal village due to the development of a subsidence zone affecting the entire valley. Around 28 buildings were damaged in this village, and people currently reside in tents. Major damage occurred during the rainfall events of July 8 to July 12. People have been displaced from their homes to temporary tent settlements, schools have been damaged, and there is a risk of further damage to infrastructure.

Fig. 28. Visible gap due to settlement of the building

Fig. 29. Debris Flow.

4. A large settlement of around 150 cm was observed in a 135 m stretch of road (Fig. 30). From the exposed part of the road, it was clear that the road was poorly constructed and did not comply with guidelines provided by IRC: SP:48-1998. The inspection of a recently constructed retaining wall revealed that it is bulging in some places and is at risk of collapse (Fig.31). Further, the old retaining wall has already been damaged due to earth pressure (Fig. 32).

Fig. 30. Large settlement in the road.

Fig. 31. Bulging of retaining wall.

Fig. 32. Damaged retaining wall.

5. Another subsidence zone of around 300 meters has been identified where the road was shifted down by 3 meters and is now being reconstructed. The newly constructed road has an average slope angle of more than 55^0, and no proper guidelines are being followed for its reconstruction (Fig. 33). There was no proper provision for drainage. The drains present along the older road have grown vegetation, resulting in the clogging of drains (Fig. 34). During the rain period of 8 July to 12 July, a bridge on the Thirtan River washed away due to river meandering, isolating only the school present from rest of the village. For 52 days, the school remained closed until a temporary wooden bridge was constructed (Fig. 35), which seemed unsafe for children and other commuters. Another significant concern was that the newly constructed school building has started to develop cracks, indicating the presence of a slow subsidence in the region.

Fig. 33. New Road construction with large slope angle.

Fig. 34 Clogging of the drain.

Fig. 35. Temporarily constructed bridge.

Fig. 36. Cracks developed in the newly constructed school building (just before monsoon).

6. Inspection of the area near Banjar revealed another subsidence zone, where four houses situated above the road and one below it suffered damage. Nearby shops also developed cracks due to the settlement. One of the houses showed a vertical displacement of about 3 meters and a horizontal displacement of about 3.5-4 meters. According to the owner, this displacement began following heavy rainfall on July 26.

7. Also, masonry buildings of the school named Saraswati Vidhya Mandir that were once connected have now shifted around 10 meters apart, indicating progressive damage (Fig.37). Even though the school building has tilted columns and developed cracks, it is still in use posing a threat to the lives of children (Fig. 38).

Fig. 37. Building shifted down due to subsidence.

Fig. 38. Tilted column of school building.

8. The subsidence zones formed in Kullu district, particularly in Tirthan and Banjar valley are progressive in nature. Slopes in these areas have exhibited slip surface failures due to a possible combination of various geological, geotechnical, and environmental factors in addition to anthropogenic activities.

9. The type and characteristics of the rocks or soils comprising the slope play a critical role in the stability of slopes. The slope material was observed to be composed of a combination of soil and weathered rock. The breakdown of rocks into fragments over time due to physical, chemical, or biological processes has weakened slopes. In addition to it the gradual removal of soil or rock particles by wind, water, or ice has eroded the slope's stability over time. The presence of geological features such as faults, fractures, or bedding planes has created zones of weakness that serve as potential slip surfaces.

Fig. 39. Slope material composed of fragmented rock and soil.

Fig. 40. Heterogeneous nature of slope material

10. Janakhla-Khani Dhar, witnessed a massive debris flow (Fig. 41, 42). The event was triggered by the subsidence of a bawari (water storage structure) on the hilltop, leading to water leakage and soil instability. Additionally, soil mass movement, including the displacement of enormous boulders, was caused by erosion and contact loss of a nala (stream) flowing from the mountaintop. Deodar trees, apple orchards, and the road partially have all been destroyed by the debris flow.

Fig. 41. Debris flow at Janakhla- Khani Dhar.

Fig. 42. Damaged orchards downhill.

11. The flash flood near HDFC Bank Sainj significantly altered the river's course, creating a new flow line that led to toe erosion of soil at the base of the hill. As per observations, up to 130 cm of land have been subsided (Fig. 43), affecting a 150-meter stretch of the hill, which includes apple and fig orchards, causing soil cracks and impacting houses situated above the affected area.

Fig. 43. Land subsidence, Sainj

12. The main market of Sainj, suffered severe damages, primarily caused by a massive flash flood resulting from heavy rainfall. The flash flood led to the flooding and destruction of houses along a 150-meter stretch of the area (Fig. 44, 45). Concrete retaining walls, initially constructed to protect structures, experienced fine particle transport and sinking due to the heavy water flow. The diverted river flow contributed to this incident. Locals said that each house in that stretch has no outlet for septic tank waste. The movement of fines, toe cuts, and the lack of discharge outlets for septic tanks also played a significant role in the settlement and further sliding of some soil mass from hills along with houses.

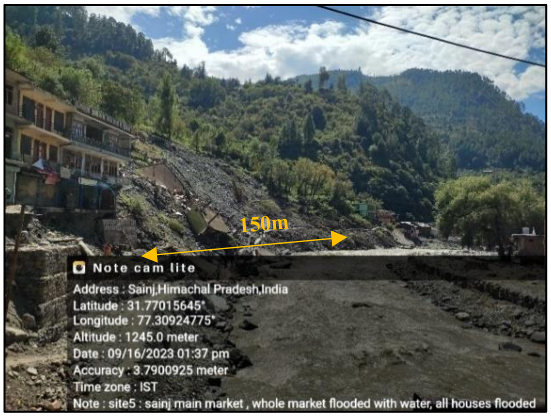


Fig. 44. Sainj main market 150 m damaged stretch.

Fig. 45. Damaged houses.

13. Another case of toe erosion in Kartah, led to settlement and the development of tension cracks on the hill's land above. 4-5 houses have been washed out partially (Fig. 46) and the road also got damaged due to settlement. The soil in the affected area exhibited slurry-like behaviour, with water seeping out.

Fig. 46. Damaged houses at Kartah.

14. During heavy rains, Neuli experienced a massive landslide spanning approximately 40-45 meters from the hilltop. The landslide involved the displacement of rocky boulders and water flow from the hill's upper reach. The event resulted in the complete damage of the road along this stretch, leading to the loss of connectivity (Fig. 47).

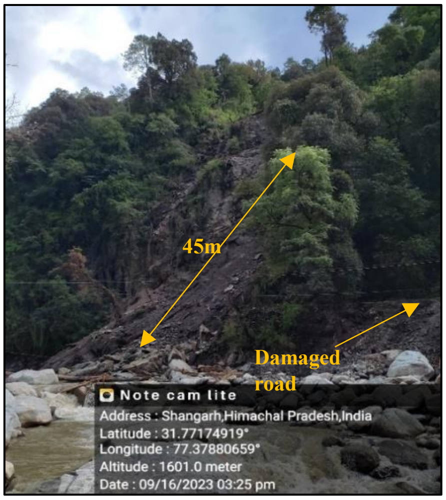


Fig. 47. Road damage due to landslide, Neuli

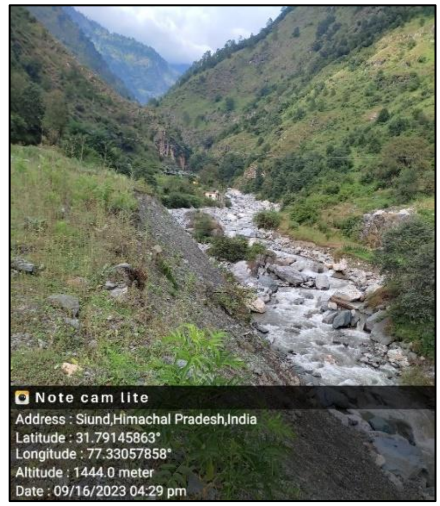


Fig. 48. Dumping site without safety walls, Sharan Bihali-Rela

15. The site, Sharan Bihali-Rela is associated with an NHPC (National Hydroelectric Power Corporation) hydropower project, where the muck was dumped (Fig. 48) without the construction of proper safety walls. Subsequently, heavy rainfall and high river flow caused the dumped muck to displace and resulted in significant damage downstream area, including infrastructure and the environment.

16. At Bihali, the rigid pavement has experienced significant damage, including breakage (Fig. 49) and the loss of pavement material (Fig. 50). The primary cause of pavement damage is attributed to erosion resulting from heavy river flow, which has exposed and displaced pavement materials.

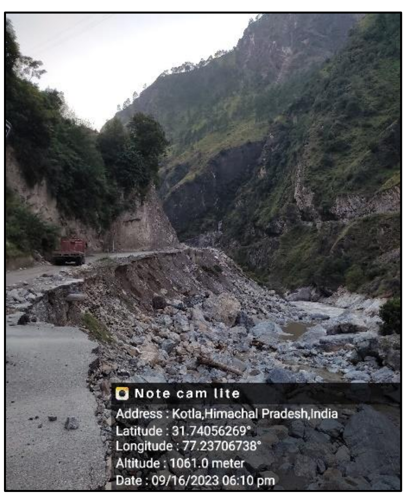


Fig. 49. Road cuts at Bihali.

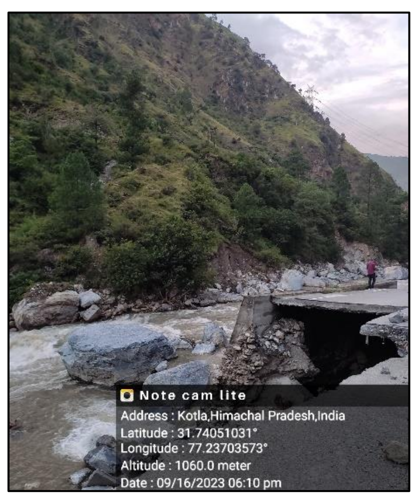


Fig. 50. Loss of pavement material due to erosion.

17. The infiltration of water into the slope during monsoon rainfall events has reduced the frictional resistance between particles or along geological discontinuities, making it easier for the slope to fail. Sudden, heavy rainfall has introduced large volumes of water into the slope, increasing pore pressure and reducing stability.

18. The slopes in the region were found to be mainly concave. Concave slopes are more prone to failure than convex slopes due to the stress concentration at the base of the slope.

19. Uncontrolled development, excavation, or construction activities on slopes have altered the natural equilibrium and triggered instability. Excavation for the construction of roads or buildings has further altered the natural slope geometry and led to the instability of slopes. Improper drainage or diversion of surface water has contributed to slope saturation and erosion, further increasing the instability of slopes.

3.4 Kullu- Manali National Highway damages:

Observations:

1. The Kullu-Manali national highway was obstructed due to the collapse of a significant portion of the road at multiple locations. The collapse resulted in the formation of large gaps in the road, rendering it impassable.

2. Noticeable erosion along the road shoulders was observed, with visible loss of soil and vegetation, underscoring the susceptibility of the roadside terrain to water runoff and undermining road stability. The eroded shoulders indicated a pressing need for effective drainage management and stabilization measures to prevent further degradation of the road infrastructure.

3. Extensive stretches of roads were completely washed away at various locations by the powerful surges of the Beas River following the monsoonal rainfall of 2023.

4. Road Subsidence was observed at multiple locations throughout the Highway stretch indicating potential instability of the underlying soil material.
5. Evidence of various types of landslides, with substantial portions of the road being obstructed due to the displacement of earth and rock debris, resulting in both partial and complete blockages. These landslides posed significant challenges to road accessibility, necessitating comprehensive mitigation measures to ensure safe and efficient transportation.

6. Observation of cracks along the road, both transverse and longitudinal suggesting probable issues related to road design and underlying soil movement.

Causative factors:

- The damages were primarily caused by rockfalls obstructing the road, sections of highway being washed away due to the force of debris flow, and increased river levels due to unprecedented monsoon rainfall.
- Disturbance in slope geometry by toe cutting for the road construction. This activity contributed to alterations in the natural slope structure, potentially leading to increased slope instability, erosion, and heightened susceptibility to landslides.
- The saturation of slope-forming material from surface runoff water during incessant rainfall has led to a substantial rise in pore water pressure, consequently diminishing the effective stress within the soil mass.
- Lack of proper drainage management. The absence of effective drainage systems contributed to water accumulation, exacerbating erosion, and fostering conditions conducive to landslides.
- Blasting through mountains with the least concern for slope stability or drainage, non-engineered roads with zero monitoring have also triggered landslides and added to destruction by cloudbursts.
- Geological factors, including the presence of weak rock formations and soil types prone to saturation, played a significant role in contributing to the observed slope failures, emphasizing the need for geotechnical assessments and slope stabilization measures in road infrastructure planning and maintenance.
- The challenging topography of Kullu, Himachal Pradesh, characterized by steep terrain and unstable slopes, was identified as a prominent risk factor, making the region highly prone to landslides

Chapter-4

Infrastructure

4.1 General

This Chapter focuses on the structural aspects of our observations during the visit. While we discuss observations from specific affected areas in detail, it is important to note that the reasons for the damages observed in other locations closely mirror those in the areas discussed here. Consequently, the recommendations provided in this chapter apply to all the damaged sites across the region.

4.2 Residential and Other Buildings

1. A building consisting of one ground floor and one upper story, with an additional rooftop shop under the ownership of Kailash Thakur, suffered a collapse due to this differential settlement issue (see Figure 51a). This residence was inhabited by Kailash Thakur, Bhagwati Devi, and Isha Thakur. The primary factor contributing to structural damage can be differential settlement at the foundation level, a consequence of subsidence in the vicinity of the road. This subsidence extended further down to impact the building's foundation. One significant observation during the inspection was the absence of any form of foundation (see Figure 51b). The prevalent local construction practice involved erecting columns over a hard stratum made of locally available boulders. This construction method led to an inadequate load transfer mechanism to the ground, resulting in cracks throughout the building walls (see Figure 52).

Fig. 51. Building collapse Kailash Niwas near Sharai

Fig. 52. Cracks due to differential settlement at various locations in building.

2. In Bandal village, more than 28 houses are affected due to subsidence, and people have been moved into the relief camps. Most of the houses were inaccessible, but the team visited one of the houses. The area has suffered a continuous settlement for over a month. Between the duration of 8 to 10 July 2023, a significant settlement took place, leading to big cracks in the building, indicating again a case of differential settlement (Fig.53). In this location, a similar pattern was followed when it came to load transfer from superstructure to substructure as in previous case. No proper provision of footing was present, and the column was raised over a stone retaining wall (Fig. 53d).

3. The school in Gishaini town is located at the toe end of the slope where the subsidence occurred. Differential settlement is observed on the school grounds. The newly constructed school building, located next to the subsidence zone, has started developing cracks at the ground level, as shown in Figure 54. Even though the cracks are not severe at present, close monitoring of the same, particularly during the rainy season, is advised.

(a)

(b)

(c)

(d)

Fig. 53. a) Settlement of slope, b) Differential settlement of the building, c) Cracks on the walls due to differential settlement of the foundation, d) Improper foundation provision.

(a) (b)

Fig. 54. Cracks due to differential settlement

4. Another subsidence zone is located in Banjaar town. Four buildings above the road have suffered damage, with one completely collapsed and 3 having large cracks, as shown in Fig. 55. The surprising thing to observe was that some buildings were still occupied, and shops were running on the ground floor. It is advised to vacate these buildings at the earliest. Below the road level, a school named Saraswati Vidya Mandir lost one of its blocks due to differential settlement, as shown in Fig 56. Again, the foundation construction practices (Fig. 56(b)) are observed to be the same as earlier ones. Some parts of the existing building foundations are exposed, and the load-carrying mechanism is not fully operational. So, close and continuous monitoring of the existing building is advised. The ongoing classes may be shifted to another building until appropriate strengthening measures are implemented.

(a) (b)

(c) (d)

Fig. 55. Cracks on building due to deferential settlement at Banjaar

(a) (b)

Fig. 56. a) Shift of school building b) improper load transfer mechanism from superstructure to substructure.

5. On 17th September, the team visited the Sainj town in Kullu district, Himachal Pradesh. The Larji-Sainj road was damaged at multiple locations on the way to Sainj town. The Sainj town is situated downstream of Parbati -III hydropower plant dam Fig. 57. On 8th July, the extreme rainfall and cloud burst event led to flash floods. The flash floods caused the collapse of 28 houses in the town (Fig. 58), and many houses are highly damaged or on the verge of collapse. The foundation of most of the houses in the town rested upon the gabion walls formed with the river boulders. Due to the huge amount of water released on the day of the extreme event,

these boulders got displaced, leading to an improper load transfer mechanism from superstructure to substructure and eventually resulting in the collapse of the buildings (Fig. 59). Like Tirthan Valley, in this case also there was no provision of proper footing arrangement and columns were raised from the stone retaining walls (Fig. 60). In addition to this there were many bad construction practises noticed in the area like floating columns, offset projections without support and brick columns observed at the site. Additionally, it is to be noticed that the houses were still occupied, and the same construction practices were continuing in under-construction buildings as well (Fig. 60).

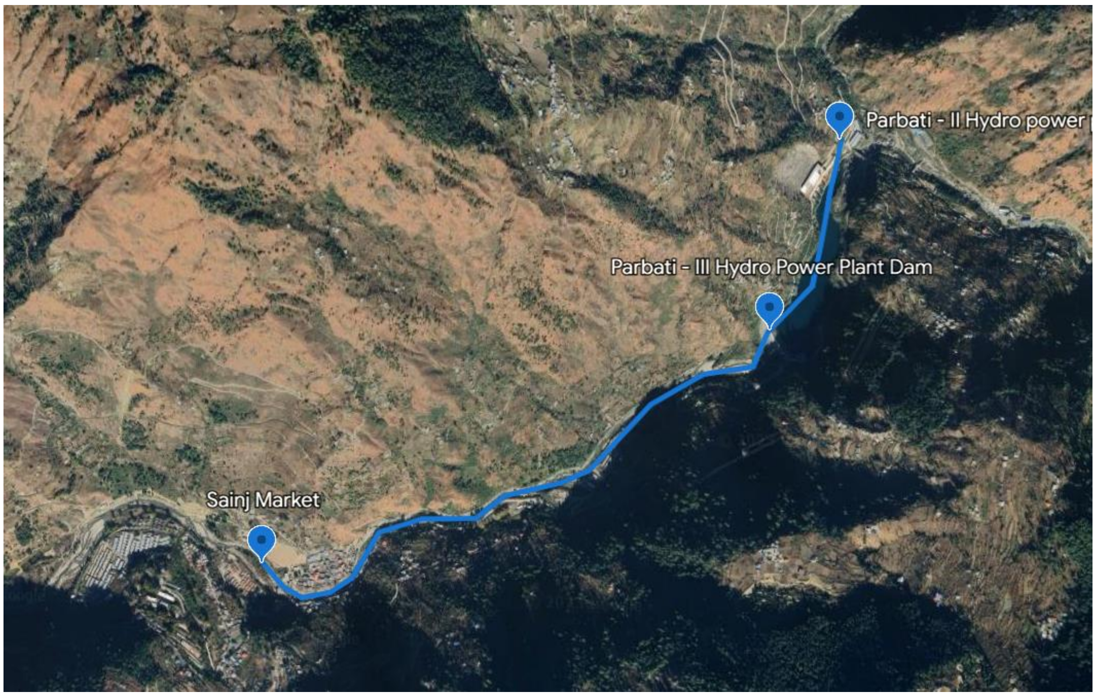


Fig. 57. Layout showing the Sainj river alignment between Parbati – II , Parbati – III and Sainj maket.

(a) (b)

(c) (d)

Fig. 58. Various building collapsed due to erosion in Sainj market.

(a) (b)

(c)

(d)

Fig. 59. Various bad construction practices in Sainj buildings: a) Brick columns is provided in structure, b) Floating column and column provided over cantilever projection, c) Improper load transfer mechanism due to missing footing, d) Insufficient tie spacing leading buckling of column.

(a)

(b)

Fig. 60. a) People staying in damaged structure putting lives in risk, b) Bad construction practices continuing in new construction.

4.3 Bridges

Moreover, reports indicate that a total of five bridges in the Kullu district have been washed away. One of these compromised bridges is visually depicted in Figure 11. The underlying causes of this structural damage can be attributed to the overall elevation in high flood levels (HFL) resulting from recent cloud burst events. In recent times, these clouds burst occurrences have grown more frequent during the monsoon season, significantly augmenting the HFL. Consequently, the bridges constructed based on previous HFL data are now at substantial risk during flood events. It is strongly advised to reassess the HFL values and subsequently update the bridge designs in accordance with these new findings.

Furthermore, an examination of the visual evidence (see Figure 61) underscores the pressing need for substantial improvements in construction quality. As Figure 61 vividly illustrates, the quality of the abutments is notably deficient.

Fig. 61. Damaged Bridge located at Jagatsukh

4.4 Damages of Electricity Distribution Systems

The reconnaissance survey reveals significant damage to electricity distribution infrastructure during flood events. Fig. 62 illustrates one such transmission tower that has suffered damage. These compromised transmission towers have added to the challenges faced during rescue operations. Therefore, it becomes imperative to identify secure locations and adhere to sound engineering practices to enhance the safety of these structures.

Fig. 62. Damaged Bridge located at Jagatsukh

Chapter-5
Recommendations

This chapter is presented to compile all the recommendations as per observations for the sections corresponding to flood, landslide, roadcuts and infrastructure.

5.1 Flood and Environment

1. Strictly regulate construction along riverbanks and demarcate floodplain zones where no permanent settlements or infrastructure should be developed. Provide adequate riparian buffer distances.
2. Implement engineered mitigation measures like embankments, retaining walls, drainage, etc., for High-Risk areas where resettlement is not possible.
3. Update infrastructure design standards using extreme event projections that account for climate change. Incorporate larger safety factors into bridge, road, and building designs.
4. Expand the precipitation monitoring network and early warning systems. Install more flood gauges and meteorological stations and link them to automated alert systems.
5. Regulate hillside development through zoning laws. Restrict construction on steep, unstable slopes. Make slope stabilization and drainage mandatory.
6. Reforest denuded hillsides and implement ecological restoration programs to increase slope stability and soil permeability.
7. Enforce strict waste disposal laws against dumping of debris along rivers. Ensure construction companies follow environmental protection norms.
8. Conduct risk assessments and disaster management drills to improve emergency preparedness and response.
9. Adopt integrated land use planning with hazard mapping and vulnerability assessments. Discourage development in high-risk zones.
10. Increase public awareness about climate risks and preparedness through education programs. Engage communities in disaster risk reduction.

5.2 Landslides and Road cuts

1. Before any construction activity, conduct detailed geotechnical surveys to assess soil stability and identify high-risk areas for subsidence and landslides. Use this information to guide construction decisions.
2. Implement and enforce zoning regulations restricting construction in high-risk subsidence and landslide zones. Ensure that new developments are located in safer areas.
3. Encourage reforestation and the maintenance of vegetative cover in vulnerable areas to stabilize slopes, reduce erosion, and enhance natural resilience against landslides.

4. Install early warning systems that can detect signs of subsidence or landslides and alert local authorities and residents in real time, allowing for timely evacuation if necessary.
5. Collaborate with geological experts and institutions to continuously monitor geological conditions in the region and seek expert advice for subsidence and landslide risk management.
6. Create specialized building codes and guidelines specific to hilly and mountainous regions, incorporating engineering designs that can withstand the unique challenges posed by subsidence and landslides.
7. Promote the use of soil stabilization techniques such as retaining walls, terracing, and slope reinforcement in construction projects within hilly areas.
8. Facilitate the formation of community-based disaster preparedness committees that are trained in response procedures, first aid, and search and rescue operations to improve overall resilience.
9. Partner with non-governmental organizations (NGOs) and international aid organizations to access additional resources and expertise in subsidence and landslide risk reduction.
10. Maintain up-to-date hazard maps that clearly delineate subsidence and landslide-prone areas and make them accessible to the public for informed decision-making.
11. Continuously conduct awareness campaigns through local media, community meetings, and schools to inform residents about the evolving risks and precautionary measures they can take.
12. Promote insurance options for property owners in subsidence-prone areas and support risk reduction initiatives that incentivize safer construction practices.
13. Periodically review and revise policies and strategies related to subsidence and landslide management to incorporate new knowledge and lessons learned from past incidents.

5.3 Infrastructure

5.3.1 For Structures on Subsidence-Prone Slopes:

1. Temporarily halt all new construction activities in subsidence-prone regions until a thorough investigation into the causes of subsidence is conducted.
2. Implement continuous monitoring of buildings in close proximity to subsidence zones to assess ongoing risks and structural stability.
3. Establish provisions for evacuating damaged buildings in subsidence-affected areas to ensure the safety of residents.
4. Conduct awareness campaigns to educate both residents and builders about different types of footing provisions, emphasizing the use of raft or combined footings to enhance structural stability.

5.3.2 For Structures Along Riverbanks:

1. Reform construction practices in riverbank areas, immediately halting ongoing new construction projects that do not adhere to proper practices.

2. Ensure that structures near riverbanks reach a stable stratum before commencing construction rather than relying solely on boulders as a foundation.
3. Promote the use of raft or combined footings in riverbank construction projects to effectively manage differential settlement, ensuring long-term structural integrity in the face of flash floods.

5.4 Overall Recommendation

1. Develop and enforce land use planning regulations that restrict the construction of critical infrastructure and densely populated areas in high-risk subsidence zones.
2. Strictly enforce building codes and standards such as IS 1893–2002, IS 4928–1993, IS 13827–1992, IS: 13920–1997, IS: 13935–1993 during the design, validation, and construction phases in fragile zones under earthquake-prone Zone-V.
3. Grant construction, incentivizing compliance, occupancy permissions, only after confirmation of adherence to relevant building codes by competent authorities, ensuring that safety standards are met.
4. Continuously update and share knowledge based on revised building codes with the public and construction stakeholders to keep them informed and aligned with the latest safety requirements.
5. Recognize the impact of tourism-driven construction in picturesque locations, which can strain resources and increase disaster risks. Engage local gram-panchayat systems and nearby academic institutions to enforce by-laws, promote disaster awareness, and build local capacity for disaster risk reduction.
6. Enhance the effectiveness of training programs such as mason training, training of trainers, and earthquake retrofitting courses by ensuring they reach the grassroots level and are accessible to the general population.
7. By prioritizing and enforcing these by-laws and related measures, communities can work towards reducing disaster risks and enhancing their resilience to natural hazards, particularly in earthquake-prone areas. Continuously update and share knowledge on revised building codes with the public and construction stakeholders to ensure alignment with safety requirements.
8. Develop and implement awareness campaigns that inform the public about government policies, by-laws, and schemes related to disaster risk reduction. Make these programs accessible and understandable to common people.
9. The region of Himachal values religious traditions and age-old practices despite recent changes. The state has faced disastrous events, but many heritage structures show robust and resilient approaches that have sustained no to minor damage.
10. Traditional architecture and construction practices are important and should be protected. Materials used in ancient constructions are worth exploring, and slight modifications should be considered to cater to climate patterns.

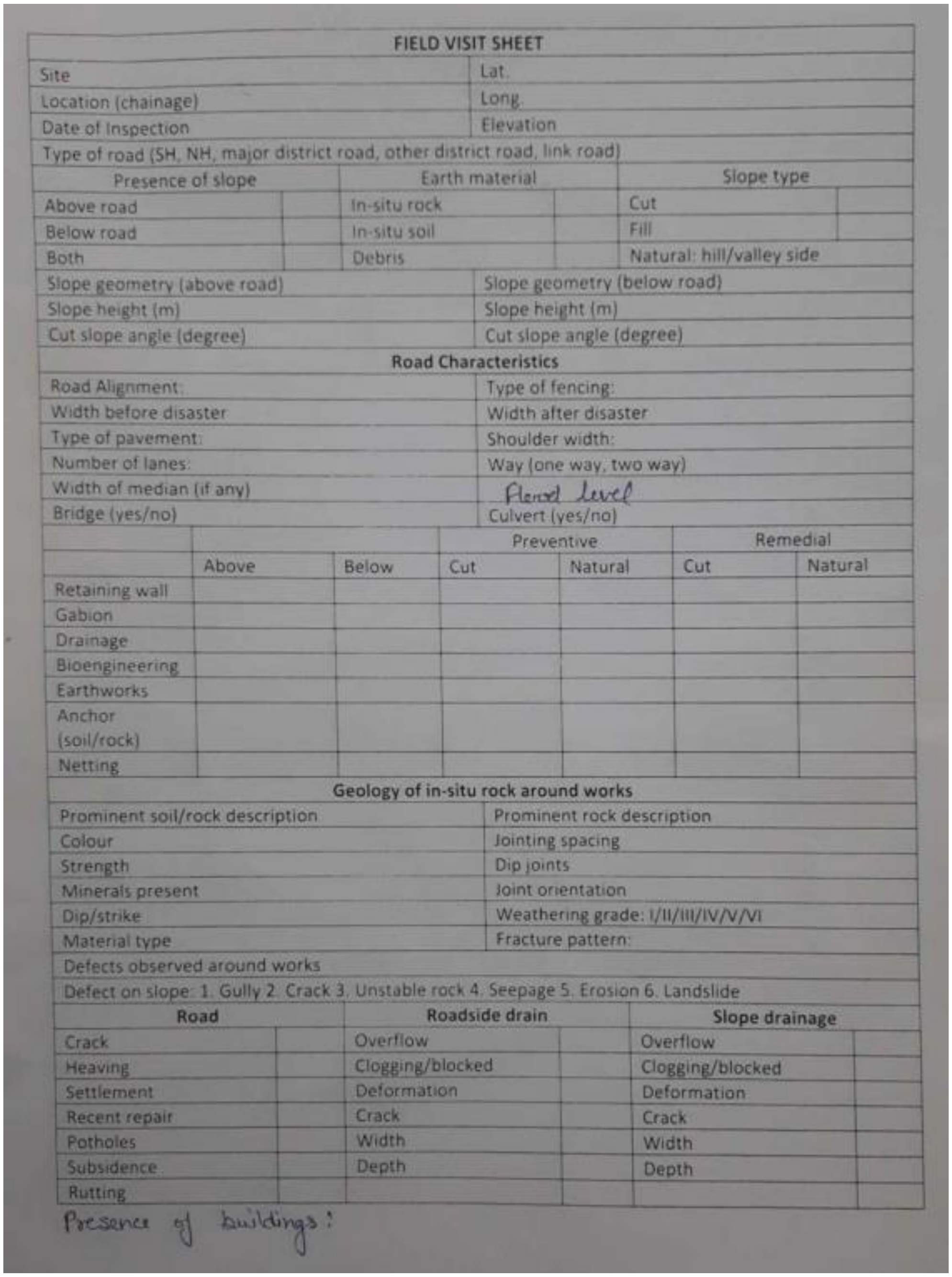
All the above recommendations are based on understanding the trigger, rainfall, and technical background of relevant hazards covered, including floods, landslides, road cuts, and infrastructure damages. The site visits are chosen in areas prone to maximum risk and under large threat. The report is extrapolated to the entire district as major hazards are limited to the above. Any specific treatment or mitigation shall need a different approach decided based on investigations and engineering design.

References

1. IS 14804: 2000 (Reviewed In: 2022) “Siting, design and selection of materials for residential buildings in hilly areas - Guidelines” of CED 56 (Hill Area Development Engineering)
2. IS 14680: 1999 (Reviewed In: 2019) “Landslide control - Guidelines” of CED 56 (Hill Area Development Engineering)
3. IS 17162: 2020 “Preparation of Landslide Risk Assessment Maps in Mountainous Terrains - Guidelines” of CED 56 (Hill Area Development Engineering)
4. IS 14243-2 (1995): Guidelines for selection and development of site for building in hill areas, Part 2: Selection and development (CED 48: Rock Mechanics)

Annexure 1

Typical data collection sheet



FIELD VISIT SHEET	
Site	Lat.
Location (chainage)	Long.
Date of Inspection	Elevation
Type of road (SH, NH, major district road, other district road, link road)	

Presence of slope		Earth material		Slope type	
Above road		In-situ rock		Cut	
Below road		In-situ soil		Fill	
Both		Debris		Natural: hill/valley side	

Slope geometry (above road)	Slope geometry (below road)
Slope height (m)	Slope height (m)
Cut slope angle (degree)	Cut slope angle (degree)

Road Characteristics	
Road Alignment:	Type of fencing:
Width before disaster	Width after disaster
Type of pavement:	Shoulder width:
Number of lanes:	Way (one way, two way)
Width of median (if any)	Flood level
Bridge (yes/no)	Culvert (yes/no)

			Preventive		Remedial	
	Above	Below	Cut	Natural	Cut	Natural
Retaining wall						
Gabion						
Drainage						
Bioengineering						
Earthworks						
Anchor (soil/rock)						
Netting						

Geology of in-situ rock around works	
Prominent soil/rock description	Prominent rock description
Colour	Jointing spacing
Strength	Dip joints
Minerals present	Joint orientation
Dip/strike	Weathering grade: I/II/III/IV/V/VI
Material type	Fracture pattern:
Defects observed around works	
Defect on slope: 1. Gully 2. Crack 3. Unstable rock 4. Seepage 5. Erosion 6. Landslide	

Road		Roadside drain		Slope drainage	
Crack		Overflow		Overflow	
Heaving		Clogging/blocked		Clogging/blocked	
Settlement		Deformation		Deformation	
Recent repair		Crack		Crack	
Potholes		Width		Width	
Subsidence		Depth		Depth	
Rutting					

Presence of buildings:

Retaining wall				
Shape				Dimensions
	Sloping	Vertical	Horizontal	Height(m)
Front face				Length (parallel to road) (m)
Back face				Embedded depth (m)
Base				Width at top (m)
Material: Composite masonry/ Mortar masonry/ Reinforced concrete/ Concrete				Width at base (m)
				Length Affected (m)
				Dia of weepholes:
Signs of distress: Crack/Tilting/Bulging/Collapse/Slip-out joint/No capacity of catch				
Distress behind wall: Settlement/Crack/Erosion/None				
Distress in front of wall: Erosion/Crack/Seepage/None				

Drainage					
Roadside (stone)		Roadside (concrete)		Lined Channel	
Lined cut-off		Counterfort		Branched	
Unlined cut-off		Horizontal		Sub-surface	
Herringbone		Check Dam		Slope surface	
Material: Masonry/Lined/Concrete/					
Signs of distress:					

Bioengineering
Description
Signs of distress:

Gabion	
Wire diameter (mm):	Base width (m):
Mesh dia (mm):	Width at top (m):
Packing: Tight/Slack/Loose	Total height (m):
	Embedded depth (m):
Signs of distress: Crack/Tilting/Bulging/Collapse/Slip-out joint/No capacity of catch	
Distress behind wall: Settlement/Crack/Erosion/None	
Distress in front of wall: Erosion/Crack/Seepage/None	

Earthworks	
Excavated	Fill
Material	Material
H (m)	H (m)
L (m)	L (m)
W (m)	W (m)
Sketch of works:	