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-- *ORIGINAL RESEARCH ARTICLE*

Assessment of Natural Hazard in the Himalayas: A Case Study of the Seti River Flash Flood 2012

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ABSTRACT

The Himalayan mountain ranges have been commonly known as one of the most vulnerable places on earth for natural hazards like landslides and flash floods. A catastrophic flash flood was witnessed in the Seti River on 5 May 2012, which exemplified how destructive it can be not just for the physical and economical loss, but also it was the loss of environment and cultural heritage sites. This paper aims to assess the flash flood event for future implications. The field study was conducted aftermath of the event, where interviews were conducted with the victims' families. It also reviewed the studies conducted by various research groups regarding this disaster. It revealed that the result of mass failure from the Annapurna IV created a temporary dam, and the sudden burst of collected water resulted in the flash flood. Overall, it took 72 lives and huge destruction of physical properties like houses, bridges, vehicles and agricultural land. The existing settlements around the Seti basin are at high risk, where it is highlighted that the concerned authority should take initiatives to minimize the possible impact by promoting awareness, installing an early warning system and building better community-based preparedness.

KEYWORDS: Flash floods, landslides, natural hazards, mountain ranges

INTRODUCTION

The Himalayan mountain ranges run for about 2400 km, which are one of the geologically most active mountain ranges on the planet. The ranges are the shelters of millions of people who are living across the mountain terrains in northern India, northern

Pakistan, Nepal, Bhutan and some areas of other Asian nations (Dahal & Hasegawa, 2008). The Himalayas, one of the youngest mountain ranges on earth is categorized by an intense energy environment because of rugged topography, high relief, steep slopes, unstable geological structures along the active tectonic process and continued seismic activities (ICIMOD, 2007). In addition to this, these areas have a complex climatic system with great seasonality in rainfall. In combination, the possibility of having natural hazards such as landslides, flash floods, etc. is significantly high in the region (Tiwari & Rayamajhi, 2018).

In the Himalaya region, landslides are scale-dependent, from the huge extent of whole mountain ranges (gravity tectonics) via a failure of single peaks to very small slope failures (Shroder & Bishop, 1998). These slope failures are hugely vulnerable not just due to their uncertainty, but also due to the possibility it possesses to trigger other natural hazards like flash floods. Flood is an unexpected outflow of the large volume of water (Ahnert et al., 1965), which considered as a destroyable natural disaster in the world. Flash floods are one of the most devastating natural disasters in terms of people affected because of their rapid and sudden occurrence, little lead time for warning and the tremendous volume of water and debris load transported with immense energy (Barredo, 2007). There are many types of flash floods that may occur such as intense rainfall floods (IRF), glacial lake outburst flood (GLOF), landslide dam outburst flood (LDOF) and flash flood due to rapid melting of snow and ice that are the common types of flash floods. They are mostly recorded in the Himalayas region.

Generally, landslides dams are formed in steep-walled, narrow valleys due to the little space for the landslide debris to spread out (Costa and Schuster, 1988). Thousands of people, their lives, livelihood and homes, along with expensive infrastructure are at great risk from flash floods in the Himalayan region every year. The threat to downstream people is likely to increase in the face of climate and environmental change (ICIMOD, 2007). In the Himalayas, flash floods are prompted by extreme cloudbursts, glacial lake outbursts, or the failure of man-made dams or dams caused by landslides, debris, ice, or snow. Flash floods can have an impact on the way upto hundreds of kilometers downstream; yet the warning time available is counted in minutes or, at the most, hours (Shrestha, 2008). He further highlighted that thousands of people, their lives, livelihoods and homes, along with expensive infrastructure investments are at great risk from flash floods in the Himalayan region every year.

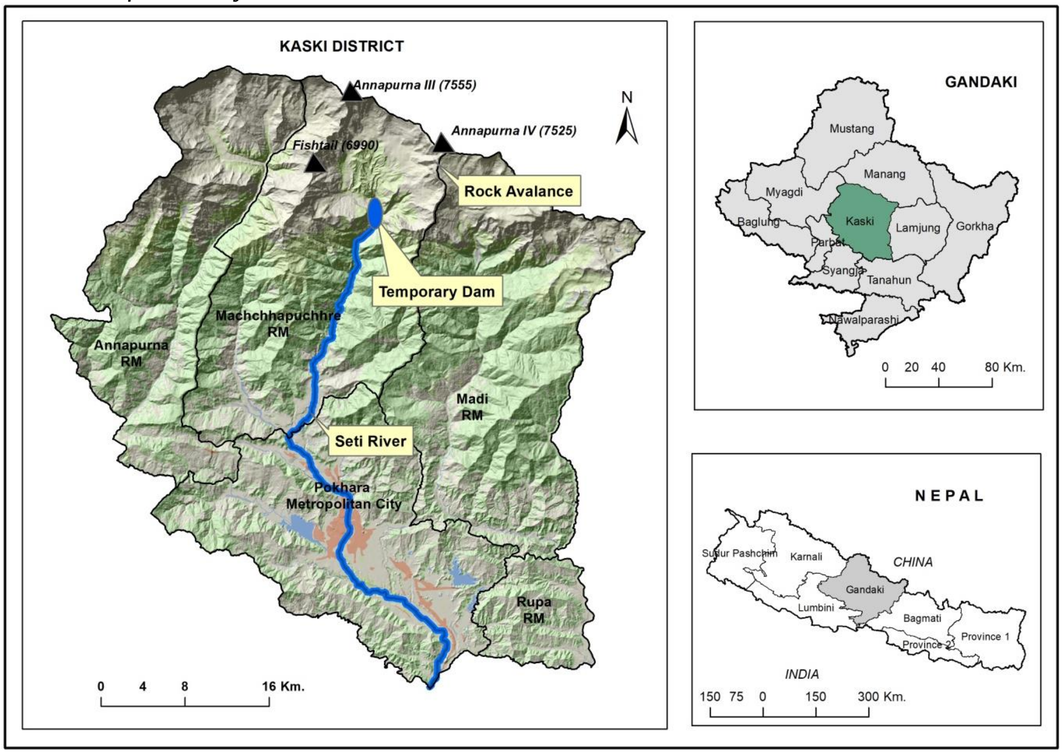
A catastrophic flash flood incidence occurred in the morning of 5 May 2012; a heavy glacial-fluvial clay sediment-laden surge rumbled down to the high-sloped Seti river bed in the northern part of Pokhara. Within a very short period, the surge immediately reached Sadal Village (then Machhapuchhre Village Development Committee), and after a few minutes, it reached Kharapani, a popular scenic picnic spot in Sardikhola VDC. The flood swallowed away drowned unsuspecting tourists, picnickers, laborers and residents of Kharapani Village. It killed 72 people and displaced many more families (MOHA, 2015). The flood also killed livestock, wiped out local livelihoods, destroyed monuments like temples, roads, community buildings and vital infrastructures such as suspension bridges, electric poles, and drinking pipes, disrupting normal water supply to Pokhara. This is one of the examples of a flash flood incident, which exemplifies how destructive and catastrophic it can be. Due to the unique topographic, geological and climatic conditions, the vulnerability of flash floods has been a presence in these areas of Himalaya ranges. Despite this severe exposure to flash flood risks, in most areas of Nepal, there are still no forecasting, warning and management systems in operation to avoid or mitigate flash flood disasters. This paper aims to assess the flash flood incident considering the case of the Seti River flash flood in 2012. It mainly focused on finding the cause of the incident and its casualties and highlighted the various possible implications, which could become a reference for other similar regions.

STUDY AREA

The Seti River is one of the perennial rivers in Nepal, which originates from the southern flank of the Annapurna Himalaya range. It is situated between the eastern face of Annapurna III and the western face of Annapurna IV to the northern part of the Machhapuchhre Rural Municipality of Kaski District in the Gandaki Province of Nepal (Fig. 1). It is also known as the disaster-prone river, which flows through the Pokhara valley floor, where vulnerability is high in terms of landslide occurrences (Poudel et al., 2020).

Figure 1

Location of the study area



The Seti River has three tributaries in the source area. The river gets its name Seti only after joining these tributaries at Tinsiri. The main tributary of Seti is originated from Annapurna III. All these three rivulets are snow-fed and therefore perennial. Since it transverses calcareous landscape, the river water is rich in calcium and looks white (K.C., 2012). It is considered a religiously sacred and economically valuable river in the western Nepal. It flows by making deep and narrow gorges on the Pokhara plain that have been picturesque tourist products for the visitors. The river openings have also been the source of sand and stone as construction materials for the Pokhara valley. Many slum dwellers are eking out their livelihood by quarrying sand and stone from the river. The location of settlements along with fragile and marginal areas of the Seti River corridor and the extraction of sand and stone from river courses have increased the risk of flood hazards. Thus, the susceptibility of both human and physical property loss is high during the flood because it might be devastated for life and property on its way to the sudden down flow.

METHODS AND MATERIALS

In this study, both primary and secondary data are used (Table 1). For the first-hand data, informal interviews with various concerned parties were conducted during the field survey. In addition, different types of ancillary data were collected to examine the casualties, causes and implications from various institutions and other government agencies. A helicopter-borne observation was also conducted for aerial outlook. In addition, the findings of other studies regarding this case are also analyzed.

Table 1

List of data used in this research

Data Type	Year	Source:
Topographical Map	1998	Survey Department, Nepal
Google Earth Image	Access 2020-12	Google Earth
SRTM – DEM data	30m.	USGS
Ancillary data	CBS 2001, 2011	CBS, Kathmandu
Local level boundary	-	Survey Department, Nepal
Field Survey	2012	Pokhara valley area

The fieldwork mainly consisted of the geological mapping at 1:25000 scale. Various studies conducted regarding this event are reviewed. In addition, other secondary sources such as books, journals, reports were also used. Maps were analyzed and presented using Remote Sensing and ArcGIS tools and techniques.

FINDINGS AND DISCUSSIONS

The overall affected area covers household settlements from the Seti River courses, particularly from Ramghat of Pokhara Metropolitan City to Jimirebari of Machhapuche Rural Municipality. The Seti River Flood Disaster Area (SRFDA) covers Machhapuchre, Sardikhola, Ghachowk, Lahachowk, Puranchaur, Lamachaur, Hemja and some areas of Pokhara Metropolitan City. According to the population census 2011, the total population of SRFDA is 289358 residing within 76,556 households. Out of the total households, only 810 (1.06%) households fall within the 50-meter margin from the Seti River. Out of total marginal households, only 163 (20%) households were purposively selected for finding characteristic features of population and settlement. For simplicity, the marginal area from Ramghat to Jimirebari were–designated as Seti River Corridor (SRC) and divided into three sections viz. Upper Seti, Middle Seti, and Lower Seti. The area above Kharapani is named as Upper Seti, [Photo:1&2] Kaskeri to Kharapani as Middle Seti [Photo:3] and Ramghat to Kaskeri as Lower Seti, [Photo:4] respectively.

Table 2

Number of household and population within the Seti confluence, 2011

Places	Number of Household	Total Population	Affected Household*
Machhapuchre	395	1729	8
Sardikhola	879	3442	7
Ghachowk	588	2707	0
Lahachowk	829	3129	0
Puranchaur	865	3597	0
Hemja	3019	12262	17

Lamachaur	1745	7027	0
Pokhara Sub-metropolitan City	68236	255465	0
Total	**76556**	**289358**	**32**

Source: (CBS, 2011); Field Survey 2012

Photo 1, 2, 3 & 4
Areas Affected by Flash Floods

[Photo: 1]. Upper part of Pokhara valley, near Talunge

[Photo 2]. Devastated Kharapani (Tatopani) Area

[Photo 3]: Highly vulnerable houses (Masina Bagar of Hemja) within 50m Seti River course.

[Photo 4]: Seti Dam and vulnerable settlement within 50m of Seti River course.

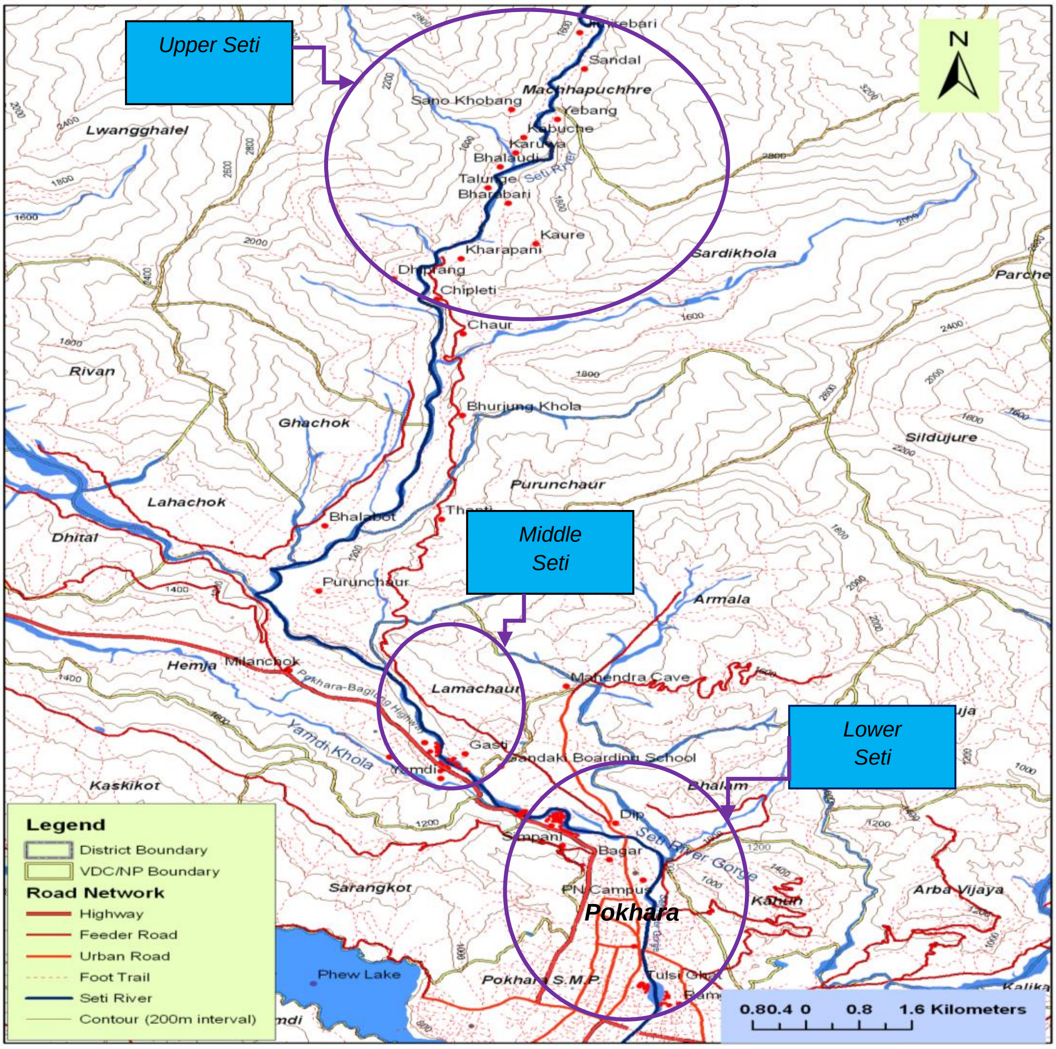
These divisions represent the spatial variation in the socio-economic profile of the population (Table 2 & Fig.2).

Human and Physical Damage

The unusual flooding in the Seti River devastated life and property along the river corridor. It had affected human lives, livestock and poultry, land and houses and physical infrastructure. Table 3 indicates that during the flood 72 people died and five persons injured. Out of 72 deaths, 28 corpses were identified in the recognizable firm whereas four corpses were identified based on available parts of the dead bodies, and the remaining 30 were never found. But injured persons have to return to their shelter after treatment. The data indicates that seven children from the flood-affected area have become orphans after the flood. Likewise, flood had swept away the domesticated livestock and poultry, particularly from Machhapuchre and Sardikhola. During flooding three buffalos, two oxen, 47 goats, and 37 chickens swept away (Table 3).

Figure 2

Location of major affected area of Seti river course



Case 1

__Mr. Kaile Magar__ is living in a new settlement at Sano Khobang. He recalled the incident, saying that he was taking lunch at the time of the flood. He said, "I heard a big sound suddenly. I came out of the house and saw around. When I turned to the riverside, I saw a terrible flood. Reluctantly I took my family members and ran to the forest to save lives. From my eyesight, the bridge linking Karuwa and Sadal was swept away by the flood. In absence of a bridge, my terrace field remained barren

because I was unable to cross the river. We were eleven family members who were displaced during the flood havoc. We are living together in Sano Khobang and constructing houses under the financial support of Annapurna Rahat Fund, Pokhara.

The loss of lands and houses was also observed during the unprecedented flood. Most households located in the Upper and Middle sections of Seti River pose land property. They had observed the damage in their land due to flood havoc. In Machhapuchre Rural Municipality, about 7.2 ha (144 Ropani) land was swept away by flood in which 5 ha (100 Ropani) was the maize field. The proportion of flood-affected among landowning households indicates that the thatched land damage had been observed by 75.00 percent, bari land damage by 56.10 percent and paddy land damage by 33.93 percent, respectively (Table 12). In terms of the proportion of landowning household, only 34.36 percent household poses paddy land and 25.15 percent poses bari land. The proportion of households having thatched land and forest is very low. Along with the land property, houses were also damaged by the flood.

Case 2

Mr. Bel Bahadur Tamang *is a 75 years of old man of Kabuche, Machhapuchre Rural Municipality. He recalled the incident in this way. Early in the morning, his wife Ash Maya had gone to the below shed located on the next side of the river to look after goats and buffalos. Suddenly, a big sound came from the upper side. He turned to the river and saw that the flood was approaching him. He said, "Myself, daughter and neighbors cried to run away but my wife returned to the shed again." In the meantime, he saw her flown away by the flood. He could not find her dead body too. Since that event, he has not crossed the river. He is helpless to live a lonely life.*

The flood had damaged 16 residential houses and eight shops from Machhapuchre, Sardikhola and Hemja areas. On 5 May 2012, six residential houses (including one water run grinder) and two shops from Machhapuchre and one residential house and six shops (including one water run grinder and one snooker board) from Sardikhola were swept away by the flood. The recurrent flood of 17 June 2012, damaged nine houses and put 60 houses at high risk in Hemja.

Case 3

Mr. Kumar Gurung *is a resident of Chaur of Sardikhola VDC. He was busy in Arghaun program (Death ritual of Gurungs) when a flood came in the Seti River. He says, "I and others heard the news that Kharapani Bazaar has been swept up by the Seti flood. Reluctantly our youth club friends including myself reached Kharapani for rescue. I saw the deserted bazaar. An old woman about 70 years old was crying for rescue. She was hanging by catching a branch of a muddy bush. We rescued her from mud. Again we saw two children in mud. We also pulled them out of the mud and sent them to Pokhara for treatment. I felt this event as terrible and hazardous.*

The unusual flood had also swept up vehicles from riversides that were deployed for hauling sand and stone extracted from the river. Seven tractors, two trucks, two motorbikes and a van were flown down by the flood.

The flood had also destroyed four suspension bridges, three kilometers of road, 25 electric poles, eight inns, two water taps and 45 meters of water transmission pipes with supporting pillars over the river. Besides these, two schools and one dairy firm were also put at high risk by the flood.

Table 3

Description of loss of life and property during Seti River flood

Lost or Damaged Items		Number
Human Life	Dead	72
	Injured	5
	Orphaned	7
Livestock and Poultry	Buffalos	3
	Oxen	2
	Goats	47
	Chickens	37
Houses and Land	Residential Houses	16
	Shops	8
	Traditional Grinders	2
	Land	7.2 ha
Vehicles	Tractor	7
	Truck	2
	Motorbike	2
	Van	1
Physical Infrastructure	Inn	8

	Suspension Bridge	4
	Electric Poles (with wires)	25
	Water Taps	2
	Drinking-Water Transmission Pipes including Supporting Pillars	45 Meters
	Blacktopped Road	1 Km
	Graveled Road	2 Km
Other Infrastructure in High Risk	Annapurna Lowe Secondary School, Machhapuchre-7	1
	Balkallyan Primary School, Hemja	1
	Houses of Masina Village	60
	Dairy Firm of Puranchaur village	1

Source: (MOHA, 2015)

Geological Implications

According to the regional geological map and cross-section of the Seti River Basin that cover the area north of Pokhara (Kargelet al., 2013), the lithology of the area was separated into several mappable units based on distinctions of lithology, presence or absence of fossils, sediment consolidation, and the position within the overall rock sequence. The lithological boundaries observed along the accessible routes were extended to the inaccessible areas based on the orientation of the beds and foliation (strike and dip). The bedrock of the area can be divided into three tectonic units, i.e., the Lesser Himalaya, Higher Himalaya, and the Tethys Himalaya separated by major regional faults, namely, the Main Central Thrust (MCT) and Annapurna Detachment (AD). The unconsolidated materials are much younger and include the Annapurna formation (calcareous silts, sands and gravels) and recent glaciers, moraines, debris flows and alluvial gravels. As we have described below, the 2012 disaster has a strong involvement from the deep Seti River gorge and the high, steep peaks of the Annapurna Range; these are erosional features developed in the rocks of the Tethys Himalaya and Higher Himalaya.

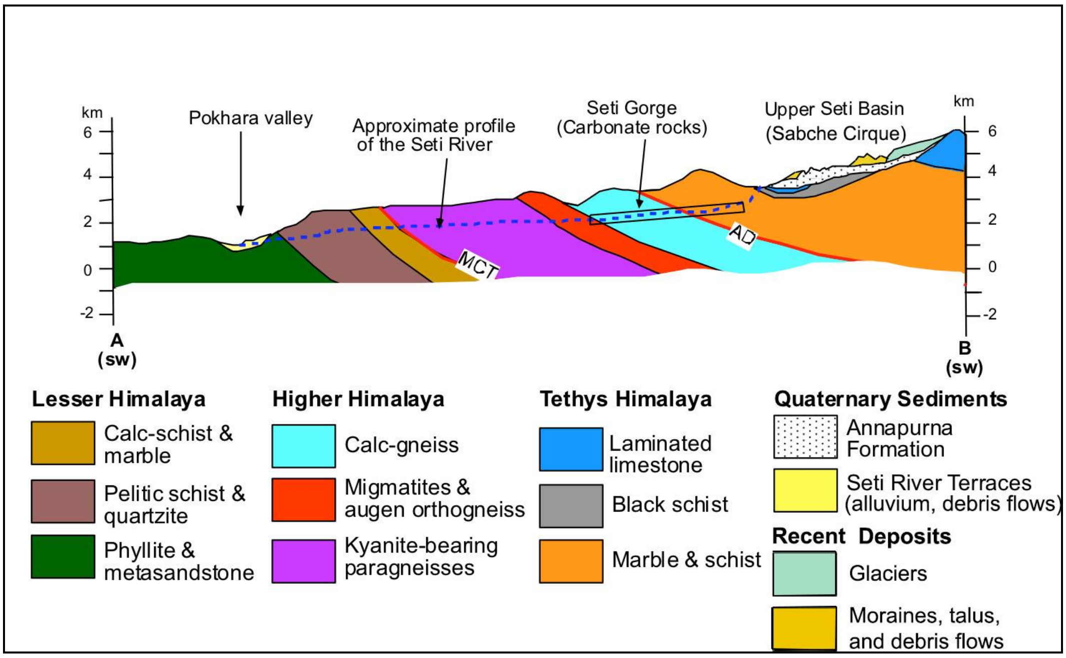
The Karst topography is formed in easily soluble rocks such as carbonates (limestone and dolomites) and evaporates (gypsum and salt). It is evident from the present geological mapping that about a 7 km stretch of the Seti River flows across the carbonate rocks (marbles, calc-schists, and calc-gneisses) (Fig. 3). These rocks are mainly composed of calcite ($CaCO_3$). The Karst topography is very common in the Pokhara valley in the carbonate cemented terraces. Mahendra Cave, Chamere Cave and Gupteshor Cave are some examples. Therefore, underground channels and caves may also be present in the Seti River gorge. This would increase the volume available to store water when the gorge is dammed and hence increase the potential flood volumes when the dam is broken.

Review of Seti River Flood Studies

There are several studies that were done about the flood havoc on 5 May 2012, of the Seti River. According to the Department of Geography (2012), a sudden flood was witnessed in the Seti River on 5 May 2012, which eventually started from the southwest slope of Annapurna IV. The findings suggest that the Annapurna formation, made of unconsolidated and poorly consolidated/weakly lithified glacial deposits and glacial lake deposits, was the source for the massive outflows of sediment and floods that formed the terraces and valley bottom of Pokhara valley. Similarly, K.C. (Seti River Flood Disaster

Figure 3

Simplified, Schematic Geological Cross-Section across the Pokhara Valley



Source: (Kargel et al., 2013)

in Pokhara Valley: Causes and Preventive Measueres, 2012) also states that the sudden occurrence of unprecedented flood havoc in the Seti River once again memorizes the earlier high flood events of geological history resulting in the extensive deposit of Pokhara Gravel from Bharabhari to Bhimad. This disastrous flood in the form of mudflow was originated from the southern flank of the Annapurna Himalayan region due to the avalanche and rock slope failure. The volume of the rock is estimated to be 22 million cubic meters. Suddenly, an enormous quantity of mudflow from the headwater area of Seti river in the form of heavy flood has made the inhabitants residing in the upper Seti valley stunned and put a great threat to the inhabitants of Pokhara city, too.

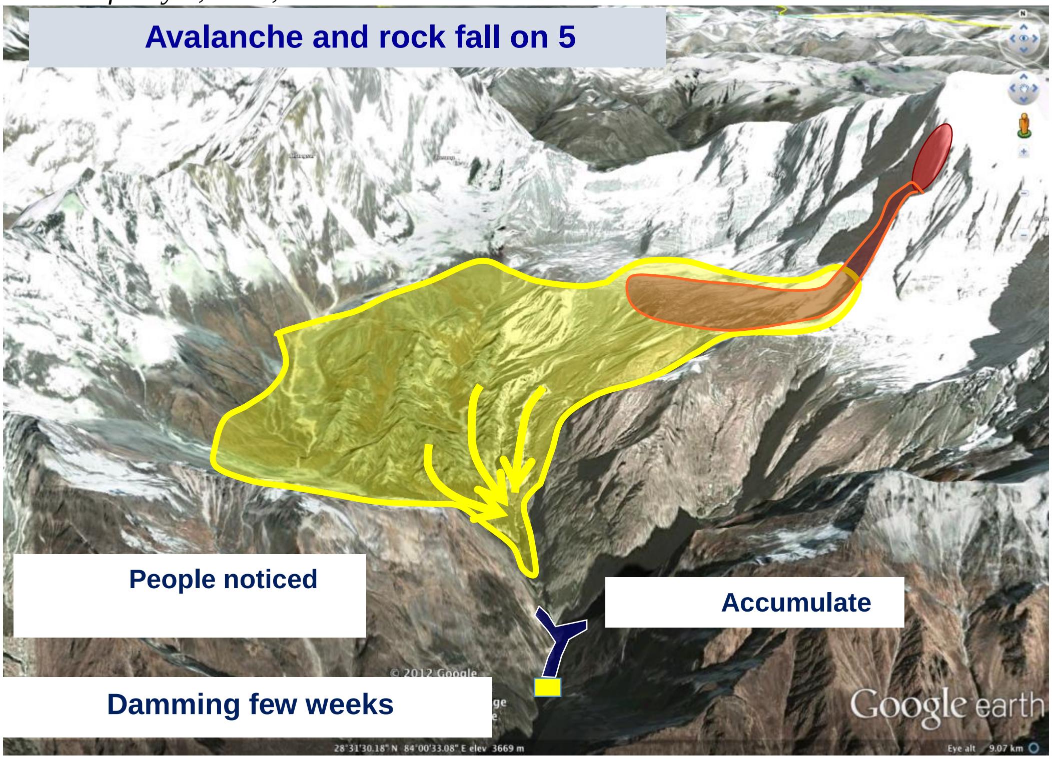
Furthermore, the hazardous condition started by a rockfall blockage, a few weeks before the disaster, of the Seti River gorge and then filling of the impoundment reservoir by early spring melting of the snowfields and glaciers (Kargel et al., 2014). It further insisted that a rock and ice avalanche from Annapurna IV (~7500 m) dislodged the previous rock fall dam when the rock-ice avalanche mixture swept into the reservoir. A hyper-concentrated slurry flow then swept down the Seti River. The possibilities of landslide dam outburst flood (LDOF) for the debris and flood event witnessed in a completely dry time. A key among the clues is the evidence that the rockfall activity into the Seti River gorge had taken place in the years and weeks before the disaster; an unusually large rock/ice/snow avalanche/landslide occurred in the minutes before the disaster; material from the avalanche/landslide, including some airborne materials and possibly some ground-flowing materials, reached as far as the Seti River gorge (OI et al., 2014).

Based on the field observations, interviews and various studies, the following are the sequences of events that occurred during this disaster.

The water flow in the Seti River was virtually cut off to Pokhara and the upstream villages in the days and weeks before the disaster, according to many eyewitness reports. This implies a nearly complete stream blockage. The blockage must have been below the point where the major tributaries within the Sabche Cirque join but above the upstream villages where the diminished (almost zero) flow was observed. This constrains the point of blockage to a short segment of the Seti River. Had the blockage been above the point where the two major tributaries (the north branch and west branch) join in the gorge area, perhaps half (more or less) of the water would have been blocked but much flow would have continued. This first clue tends to rule out the glacier ice and the Annapurna formation as hosts of the reservoir, but it allows the gorge and also could allow any karstic cavernous spaces connected to the gorge that could have been filled due to damming of the gorge [Photo:5].

Photo 5

Essence of May 5, 2012, Seti River Flash Flood



When the Seti River was blocked, a trickle continued but changed its color from the usual white caused by abundant suspended rock flour. ("Seti" means "white," so it is the White River) Hence, water draining from the glaciers and the Annapurna formation was blocked, leaving only small amounts of water runoff from points below the glaciers and the Annapurna formation. This again points to a blockage in the gorge area below the Annapurna formation and below where the two major tributaries join.

The satellite observations have definitively identified several discrete erosional events along the walls of the gorge. Our observations via satellite and helicopter have identified the biggest of these as a site of recurrent rockfalls into the gorge**.** The helicopter-borne observations show a white sediment staining or covering of the walls of the gorge consistent with it having contained a sediment-laden reservoir in the gorge**.**

Our observations have indicated that the gorge volume is far greater than we had initially believed, and so it could have contained enough water and sediment volume to have explained the slurry flood disaster**.** The gorge is both wider in some sections and far deeper (exceeding 500 m) than we had suspected at first [Photo: 6]. The gorge geometry is such that a contained volume of more than 107 m3 is possible, i.e., enough to explain the 2012 outburst flood volume. Furthermore, there remains some speculation with some limited supporting observations that the gorge geometry may widen at the bottom with karst cave-like structures, which may add to the present estimations of contained volume. Consequently, our earlier assessment that the flood water volume required multiple sources is no longer a requirement. The gorge alone with or without additional water-filled karstic caverns-might be sufficient to explain the flood volume.

Photo 6

Flattened forest blown down by the avalanche winds. Gorge starts from Upper Seti basin nearly 3000m height from asl

IMPLICATION FOR FUTURE HAZARDS

Landslide, Rockfall and Rock Avalanche

The bedrock in the upper Seti Basin is quite unstable due to the steep slopes and high relief and the known history of large and small mass movements. A huge rock sliding along the bedding plane (plane failure) is quite common in the area. Freeze and thaw action of water is playing a significant role in the failure of slopes, including failure according to knickpoint theory (García & Mahan, 2012). A large rock sliding along the gorge wall of the Seti River may cause frequent damming of the Seti River. The similar flash floods are thus possible in the future by the failure of the landslide dam.

Ice Avalanche

Ice from a cornice was involved in the 5 May 2012 avalanche. Hanging glaciers are also present high on the walls of the Sabche Cirque. Collapsing ice could impart enough energy to the unconsolidated sediment of the Annapurna formation to generate large sediment of mass movement. An ice avalanche into a glacial lake could generate a GLOF.

Debris Flow Hazard by Liquefaction

The Annapurna formation is loose sediment of about 500-600 m thick (more in some areas) covered in the upper part by glaciers and kettle lakes. In the spring and summer, huge amounts of ice and snow are melted and this meltwater saturates the sediments, potentially weakening the cohesion of the sediment. The strong monsoon rains could likely saturate the sediment. Many debris flows are observed in the Annapurna formation, so we pressure that sediment flow is a frequent occurrence. The recent debris flows we have observed are relatively small, and events of that magnitude do not pose a threat. However, if a strong earthquake occurs in this situation, or if a large discrete monsoonal rain event adds onto already-saturated conditions, the sediment may liquefy from a large area and flow downstream, and potentially cause a huge disaster in the Pokhara valley.

CONCLUSION

The Seti River flash flood was one of the examples of catastrophic flash flood disaster, which consequently took 72 lives and destroyed many physical properties. In brief, consisted of a rockslide into a gorge and the formation of an impounded lake in the gorge; then a huge rock and ice avalanche off Annapurna IV, which violently swept debris into the impounded lake and caused the rupture of the gorge dam, and thus unleashing of the flood. Additional sources of water may have been incorporated into the avalanche mass movement, including small supraglacial ponds, subglacial water bodies, wet snow and frictional melting of snow and ice. The ingestion of ancient lake sediments, and especially powder-like silt, added much mass to the avalanche flows and is what caused the high sediment content of the floodwaters.

The disaster caused a significant damage to properties like houses, vehicles, livestock, bridges, agricultural land and so on. Many children became orphans, which brought the uncertainty of their upbringings. It indicates that disasters like this not only impact economically but also impact hugely from a social and environmental perspective. On the other hand, geologically, the Seti River is composed of soft soil with lime mixed, therefore, it remains fragile all the time, which ultimately demands supervision along with the application of both preventive as well as protective measures.

Rapid urbanization is observed in the Pokhara valley, which forced to have settlements along the basin of the Seti River, which are hugely considered as vulnerable to a disaster like this one. So, the settlements on the sides must be taken care of, if found risky, they have to be shifted to the safe side. Likewise, the damage that was made by this event could have minimized if an early warning would have made in those areas. However, the lack of effective early warning systems further exaggerated the losses. Moreover, raising awareness and knowledge about flash floods at all levels among communities, practitioners and policymakers would also enhance preparedness. In addition, empowering communities could play a central role in the flash flood management, including preparedness, adaptation and mitigation.

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REFERENCES

Ahnert, F., Leopold, L. B., Wolman, M. G., & Miller, J. P. (1965). Fluvial processes in geomorphology. *Geographical Review*, *55*(3), 452. https://doi.org/10.2307/213147

Barredo, J. I. (2007). Major flood disasters in Europe: 1950–2005. *Natural Hazards*, *42*(1), 125–148. https://doi.org/10.1007/s11069-006-9065-2

CBS. (2012). National Population and Housing Census 2011(National Report). *Government of Nepal, National Planning Commission Secretariat, Central Bu Reau of Statistics*.

COSTA, J. E., & SCHUSTER, R. L. (1988). The formation and failure of natural dams. *Geological Society of America Bulletin*, *100*(7), 1054–1068. https://doi.org/10.1130/0016-7606(1988)100<1054:TFAFON>2.3.CO;2

Dahal, R. K., & Hasegawa, S. (2008). Representative rainfall thresholds for landslides in the Nepal Himalaya. *Geomorphology*. https://doi.org/10.1016/ j.geomorph. 2008.01.014

Department of Geography. (2012). *Prelininry Study Report of Seti River Flash Flood.* Pokhara : Prithvi Narayan Campus.

García, A. F., & Mahan, S. A. (2012). The influence of upper-crust lithology on topographic development in the central Coast Ranges of California. *Geomorphology*, *138*(1), 243–262. https://doi.org/10.1016/j.geomorph.2011.09.009

ICIMOD. (2007). *Information on the Occasion of World Flash Floods in the Himalayas* (Issue July 1993). https://www.weadapt.org/sites/weadapt.org/files/legacy-new/placemarks/files/ 52fa5 cbedbde2icimod-flashfloods07a.pdf

Kargel, J., Leonard, G., Paudel, L., Regmi, D., Bajracharya, S., Fort, M., Joshi, S., Poudel, K., Thapa, B., & Watanabe, T. (2013). The 2012 Seti River flood disaster and alpine cryospheric hazards facing Pokhara, Nepal. *EGU General Assembly Conference Abstracts*, *16*. http://adsabs.harvard.edu/abs/2014EGUGA..1612448K

Kargel J. Leonard G, Regmi D, Joshi S, Poudel K, Thapa B, Watanabe T, Fort M, P. L. (2013). Causes and human impacts of the Seyi River (Nepal) disaster of 2012. *Glacial Flodding and Disaster Risk Management*, 0–9.

K.C., K. (2012). Seti River flood disaster in Pokhara Valley: Causes and preventive measueres. *7*. Pokhara : The Himalayan Geographers.

MOHA. (2015). Nepal disaster report 2015. ~~In~~ *Government of Nepal* (Vol. 58, Issue 12). https://doi.org/10.1128/AAC.03728-14

Oi, H., Higaki, D., Yagi, H., Usuki, N., & Yoshino, K. (2014). Report of the investigation of the flood disaster that occurred on May 5, 2012 along the Seti River in Nepal. *International Journal of Erosion Control Engineering*, *7*(4), 111–117. https://doi.org/10.13101/ijece.7.111

Poudel, K. R., Hamal, R., & Paudel, N. (2020). Landslide susceptibility assessment: identification and hazard mapping of Gandaki Province, Nepal. *Prithvi Academic Journal*. https://doi.org/10.3126/paj.v3i0.29555

Shrestha, A. B. (2008). Resource manual on flash flood risk management: Module 2: Non-Structural measures. *ICIMOD*. http://lib.icimod.org/record/7892

Shroder, J. F., & Bishop, M. P. (1998). Mass movement in the Himalaya: New insights and research directions. *Geomorphology*. https://doi.org/10.1016/S0169-555X(98)00049-X

Tiwari, K. R., & Rayamajhi, S. (2018). Devastating monsoon: Water induced disaster management practices in Nepal. *Forestry: Journal of Institute of Forestry, Nepal*, *15*, 57–76. https://doi.org/10.3126/forestry.v15i0.24921