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Geological hazards in Pokhara Valley, western Nepal

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ABSTRACT

The Pokhara Valley is mainly occupied by coarse grained sediments weakly to strongly cemented by calcareous cement. These sediments are the result of at least 3 major episodes of debris flow events along the Seti River originating from the Annapurna Region. They are named as the Tallakot, Ghachok and Pokhara formations (Yamanaka et al., 1982). The debris flow had dammed the tributary valleys (Gurung, 1970) during the corresponding period contributing the development of lacustrine environment (Fort, 1986), of which several examples can be cited. The material of the Tallakot debris flow episode, which is the oldest one, was also found about 3 km upstream of the Mardi Khola (a major tributary of the Seti River) diverting about 90° from its main flow course where it dammed the stream with the creation of lacustrine environment behind. Although the age of the different debris flow deposits giving rise to the corresponding formations in the Pokhara Valley has yet to be determined, the age dated for the latest event, i. e., for the Pokhara glacio-fluvial event as 600-1100 years before present (Yamanaka et al., 1982, and Fort, 1987), is debatable because of lack of any historical evidence.

In all the debris flow events the material is dominated by calcareous sediments both in clasts and in matrix. Because of their high content of calcareous material the calc-rudites so deposited are suffering from karstification of different intensity producing solution channels, chimneys and pinnacles forming underground caves and cavities. Although the material deposited by the Tallakot debris flow event is also suffering from the karstification but the material deposited by the Ghachok debris flow event has been found to be most susceptible for karstification. The importance of the karstification in the Ghachok Formation is also increased because the city core area of Pokhara is underlain by this formation.

Geological hazards in the Pokhara Valley can be divided into debris flow hazard, karst hazard and landslide hazard.

INTRODUCTION

Pokhara is a unique intramontane valley elongated towards NW-SE direction from Bharabhari in the north-west to Bhimad in the south-east. It is located almost at the centre of the Kingdom of Nepal. Total length of the valley is about 50 km. and average width is about 5 km bound by latitude 27° 55' N to 28° 25' N and longitude 83° 45' E to 84° 10'E. The aerial distance between the peak of Machhapuchhre (6993 m) and the Pokhara town (853 m) is only about 30 km. The unique drop is without any intermediate mountain chain in between.

The paper, after giving short glimpse on the major contributions by various authors about the Pokhara Valley, describes in short the geology of the clastic sedimentary deposits, highlights geological hazards related to these clastic sediment and their impact on the Pokhara Valley. The paper also suggests some mitigative measures to minimize the impacts.

PREVIOUS WORKS

Several Nepalese and foreign geoscientists have studied the Pokhara Valley and drawn various conclusions such as:

Gurung (1965) in his doctoral thesis concluded that Pokhara is a tectonically controlled valley. The lakes around the valley are formed due to the damming of tributaries of the Seti River during the catastrophic debris flow event which is responsible for the deposition of his "Pokhara gravel". He also suggested that rise of the Mahabharat Range and subsidence of the valley caused the thick accumulation of the Quaternary deposit.

Hagen (1969) is of the opinion that Pokhara is a tectonic valley and there existed a big Pokhara lake which was filled up by a catastrophic event of debris flow and the present lakes are the remnants and pushed aside lake of the bigger Pokhara lake.

Hormann (1974) attributed the cause of formation of the valley to tectonic subsidence of the basin itself. He studied the valley fill deposit and divided it into three groups and attributed them to three glacial ages. He is of the opinion that tectonic subsidence in the basin and glacial advance in Great Himalayas are the cause of the thick gravel deposit of the Pokhara Valley.

Yamanaka et al. (1982) divided the Quaternary deposit into seven formations. They described them geologically and geomorphologically. They compiled a Quaternary geological map of the Pokhara Valley and negated the existence of big palaeo-Pokhara lake.

Fort (1987) examined whether the structural and climatic factors can be related to the steep topographic and bioclimatic gradients and explain the possible deformation along the Main Central Thrust (MCT) by the help of the study of the Pokhara basin. She concluded that:

(1) Rapid catastrophic episode of the Pokhara gravel aggradation can also serve as a model for the geomorphological evolution of the "Higher Himalayan Front" (HHF) in the central part of the Himalayas.

(2) It also demonstrates that how the steepness of the still rising front is maintained

GEOLOGY

The Pokhara Valley floor sediment is composed mainly of detritus sediments brought by the Seti River fluvioglacial/debris flow action during the Pliestocene (?) period. The stratigraphy of the Pokhara Valley is presented in Table 1.

Kuncha Formation

The basement rock of the Pokhara Valley is represented by highly to moderately weathered phyllites and medium to thickly bedded gritty quartzites. The individual bed of quartzites vary from 5 cm to about 1 m, and that of phyllites from few millimetres to several centimetres. The rocks in the surrounding area dip south west consequently developing signs of instabilities on the south west facing slopes as in the Kaon hill. Except at the river bank, the bedrock is covered by 1-3 m thick blanket of colluvial and/or residual soil.

Table 1: Stratigraphy of Pokahara valley.

Age	Formation	Thickness	Lithology
Recent	Alluvial (Fan/Plain) deposit	10 m	Sandy boulder and gravel. Alluvial fan dominantly containing metasediments and alluvial plain composed of boulders of gneiss, granite, quartzite, limestone and metasediments.
Holocene	Pokhara Formation	80 m+	Fluvioglacial gravels of mostly limestone with subordinate gneiss, granite, quartzite and schist.
Holcene	Phewa Formation	20 m	Lacustrine calcareous silty clay and clayey silt.
Pleistocene?	Ghachok Formation	100 m	Debris flow deposit highly cemented calcareous with limestone clasts of variable size.
Pleistocene	Indi Khola Formation	5 m	Lacustrine deposit up to 3 m thick peat with sandy gravel lenses
Pleistocene	Tallakot Formation	100 m	Matrix supported highly cemented calcareous fanglomerate of debris flow origin composed of mainly limestone with granitic and gneissic clasts.
Precambrian	Kuncha Formation	6 km+	Gritty phyllite and quartzite.

Tallakot Formation

The Tallakot Formation got its name from the Tallakot village about 5 km north of Pokhara (Fig. 1). The name was first used by Yamanaka et al. (1982). The clasts of the Tallakot Formation, which are exclusively of limestone, are strongly cemented by calcareous material and are angular to sub-angular in shape.

From the field evidence it can be suggested that the fluidity of the material of the Tallakot Formation was more than that of the Ghachok Formation (to be described later) because the matrix content of the former is more than that of the later and also the size of the clasts in the later is bigger. The weathering product of the Tallakot Formation is dark yellow soil and the morphological feature is clearly recognizable. It is producing the mega-pinnacles similar to that of the highly karstified limestone zone elsewhere. Topographically, the Tallakot Formation is either occupying the elongated hills as that of Tallakot or the slopping terrace Khodarjung. Sink hole development was observed in the Tallakot Formation occasionally. Exposed thickness of this deposit is about 100 m.

Indi Khola Formation

The Indi Khola Formation is the lacustrine facies developed just after the accumulation of the Tallakot Formation. From the field relation it is clear that the Indi Khola Formation is deposited in the tributary valleys of the Seti River which was dammed by the Tallakot debris flow event. The Indi Khola Formation is composed of silty to clayey laminated soil of yellow colour with or without peat formation.

Ghachok Formation

The Ghachok Formation got its name from the Ghachok village about 15 km north of Pokhara. The name was first used by Yamanaka et al. (1982). The distribution of Ghachok Formation in the Pokhara valley is very widespread. The Ghachok Formation is composed of calcareous cemented fanglomerate, i.e., calc-rudite. Although the major part of the cement of the Ghachok Formation is composed of calcareous silt and clay, cementation due to the calcareous solution is also common. The size of the grains varies from huge boulders to silt. A majority of the clasts are composed of limestones, however, clasts of quartzites, gneisses and granites are also observed. The clasts in most cases are floating in the matrix and the shape is angular. The Ghachok Formation is either unconformably overlying the irregular basement surface of the rocks of the Kuncha Formation or over the Tallakot Formation. The Ghachok Formation at places show imbrications and even sometimes bedding like feature which does not continue for longer distance. Observed thickness of the Ghachok Formation is about 100 m in the central part of the Pokhara Valley.

The top of the Ghachok Formation is covered by a thin (1-3 m) loose pale greenish silty soil (a weathering product of the Ghachok Formation itself) in the central city area of Pokhara. In the southern part, it is covered by slightly cemented sandy gravels of the Pokhara Formation.

The Ghachok Formation is suffering from mature karstification. It is being composed of various types of clasts having different weatherability, hence, it is suffering from differential weathering. Frequent sink holes and pinnacles with solution chimneys are the typical character of the Ghachok Formation.

The calcareous cementation in the Ghachok Formation is not uniform everywhere. Towards the centre of the valley, the cementing is stronger than at the marginal part. The reason for this is attributed to the addition of extra non-calcareous sediment and solution from the slope wash in the foot-hill area. The difference in the nature of these two high and low content of calcareous cementing material can be recognized by the presence of high degree of instability in the area occupied by low calcareous content material (Fig. 2). Well developed vertical to sub-vertical joints parallel to opening were also found in the Ghachok Formation.

Phewa Formation

The name Phewa Formation, first used by Yamanaka et al. (1982) is assigned to the lacustrine deposit formed in the downstream reaches of the tributaries of the Seti River. This was formed due to the damming of the tributary valleys of the Seti River during the Ghachok debris flow event.

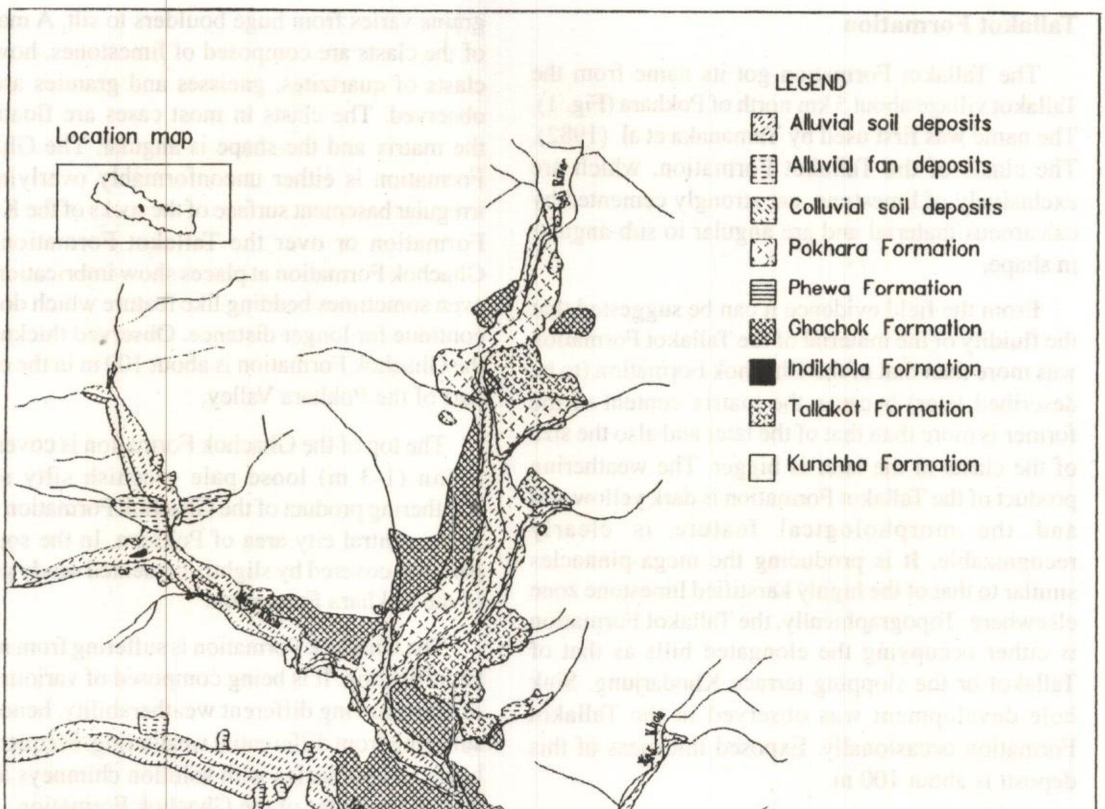

Fig. 1: Engineering geological map of the Pokhara Valley.

Fig. 2: Photo showing the marginal zone of Ghachok formation in contact with colluvial material.

The Phewa Formation is well stratified calcarenite to calcisiltite. The material is porous and comparatively weak (~1 Mpa) in natural condition. At places underground erosion and channel development was observed especially in the area of Davi's fall (Koirala 1994) and Mahendra Cave. The Mahendra Cave in the north and Gupteswor Cave in the south of the Pokhara town are developed in the Phewa Formation.

Pokhara Formation

The name is derived from Pokhara area and used first by Hormann (1974). The Pokhara Formation consists mainly of silty to sandy gravels. The cementing material is calcareous silt. The Pokhara formation is rather loosely cemented coarse gravel of fluvial origin in general. Hence, it can be suggested that the gravels of the Pokhara Formation possibly are the old terrace deposit of the Seti River and reworked to be deposited as the Pokhara Formation. Most of the material is composed of limestones. There are also some clasts of quartzites, granites and gneisses. The limestone clasts are relatively more rounded than that of the quartzites and granites. In this formation, calcareous crusts, 'hard pan' of Yamanaka et al. (1982), were observed in different horizons, but those crusts are not continuous for a longer distance. Water logging is rarely observed in Pokhara. Permeability of the Pokhara Formation is very high due to the presence of the low amount of matrix and the clast to clast contact of granular material. One hour after a heavy rain, the ground surface becomes dry.

Alluvial Deposits

Alluvial soils are mainly deposited along the the Seti, Phurse and Kali Khola banks. They consist mainly of the boulder to silt sized material composed of gneisses, granites, schists and limestones. The deposit is renewed every year during the rainy season. The material of this deposit is loose and this material can be named as sandy gravel (GP) to gravelly sand (SP) according to Unified Soil Classification System (USCS).

Alluvial Fan

Alluvial fans are deposited by streams at or near to the confluence with the bigger streams such as the Seti River. The material consists mainly of gritty quartzites and phyllites of the local origin. This type of soil is mainly located at the foot hills where the streamlet carrying the material is no more able to carry the bed load. According to the USCS, the soil can be named as silty sandy gravel (GM-SM).

GEOLOGICAL HAZARDS AND THEIR IMPACTS IN POKHARA

Among the various geological formations, the Ghachok Formation, on which major part of the Pokhara town area is situated, is suffering from intense and mature karstification. Hence, the threat due to sink hole development, one of the consequence of karstification is of major concern in the Pokhara town area. The geological hazards (Fig. 3) which needs particular attention in Pokhara are:

- Debris flow hazards
- Karstification hazards and
- Landslide/river bank collapse hazards

Debris flow hazards

Debris flows are slurries of viscous soil and boulders which can move at high velocities over rough surfaces (Selby, 1990). Observing the nature of the clastic sediments and the geological evidences collected by various authors, it is clear that at least three major events of huge scale debris flow occurred in the Pokhara valley. Among the three phases of debris flow deposits, the latest is suggested to be about 600-1100 years B.P. (Yamanaka et al., 1982, and Fort, 1987). The carbon dating of the palaeosoil samples, collected by the authors from different parts of Pokhara, indicates two distinct phases of debris flow one being 11230±230 and other 1830±75 years BP. The analysis was carried out in the laboratory of Bundesanstalt für Geowissenschaften und Rhostoffe (BGR), Germany.

About the probability of large scale debris flow event in Pokhara, the present authors totally agree with the statement made by Fort (1987), who stated that "Probably the area is most prone to catastrophic/ unpredictable geomorphological hazards and creates a permanent, low recurrence but significant threat for the local population".

Karstification hazards

All the debris flow deposits of various geological ages consisting chiefly of calcareous material have undergone different stages of karstification. The Pokhara Formation being youngest the karstified features are least developed in it. The rest two Tallakot and Ghachok formations are maturely karstified and had left the effects in the form of sink holes, pinnacles, solution chimneys, etc.

Although the karstification has also occurred in other formations, the karstification in the Ghachok Formation is of major concern because the major part of the Pokhara town is over it. Several sink holes and caverns can be seen in and around the town area and the marginal parts of the sediment deposit. There are various cases of damages to houses and farmlands due to sink hole formations (Fig. 4). The Tallakot Formation was not found as intensely karstified as the Ghachok Formation nevertheless sink holes and mega-pinnacles are typically developed in it.

The Pokhara Formation in the south of airport was found to suffer washing out of the calcareous cement leaving the gravel packed in mud matrix. This type of anomaly was probably due to the seepage water from the nearby canal. In this case void spaces at places were also observed and on the floor of the void mud was observed.

Not only the granular formations of the Pokhara region but also the compact calcareous silty and sandy deposit (Phewa Formation) are also suffering from karstification. Best examples are the caverns like Davi's fall and Mahendra cave developed in it.

Landslide hazard

In this paper, evaluation of the landslide hazard does not include the catchment slopes of the Pokhara Valley. It is restricted to the bank collapses along the Seti River and its major tributaries. Bank collapses, block fall and block sliding resulting from the development of the tension cracks parallel to the Seti gorge is a common phenomena in Pokhara. Besides the collapsed Seti bridge, the other Seti crossing sites are the places where huge blocks of the Ghachok Formation separated from the bank walls can be seen along the Seti River (Fig. 5). On the contrary, Mahendrapul is the area where such

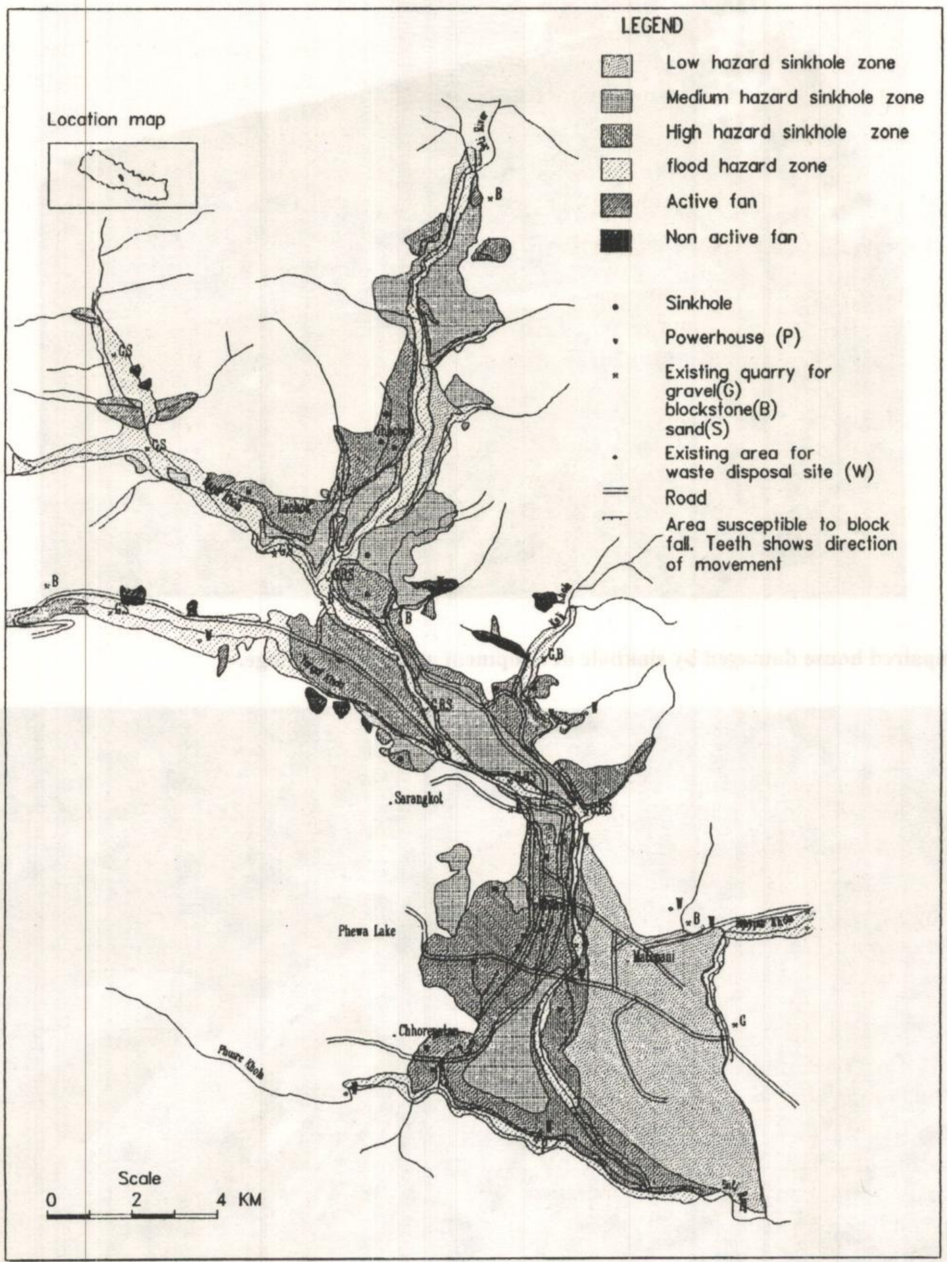

Fig. 3: Hazard map of the Pokhara Valley.

activity does not occur. The reason of such anomaly is not understood clearly.

In this context, the edges of the banks of the Seti River and its tributaries should be considered as block fall and bank collapse hazardous area. Besides the gorge area the slopes of the catchment of the Seti River are also vulnerable to landslide. Fresh landslides can be seen on the hill slopes around but the evaluation of each slope unit in terms of degree of hazard is yet to be carried out.

Fig. 4: A repaired house damaged by sinkhole development at Ghachok village.

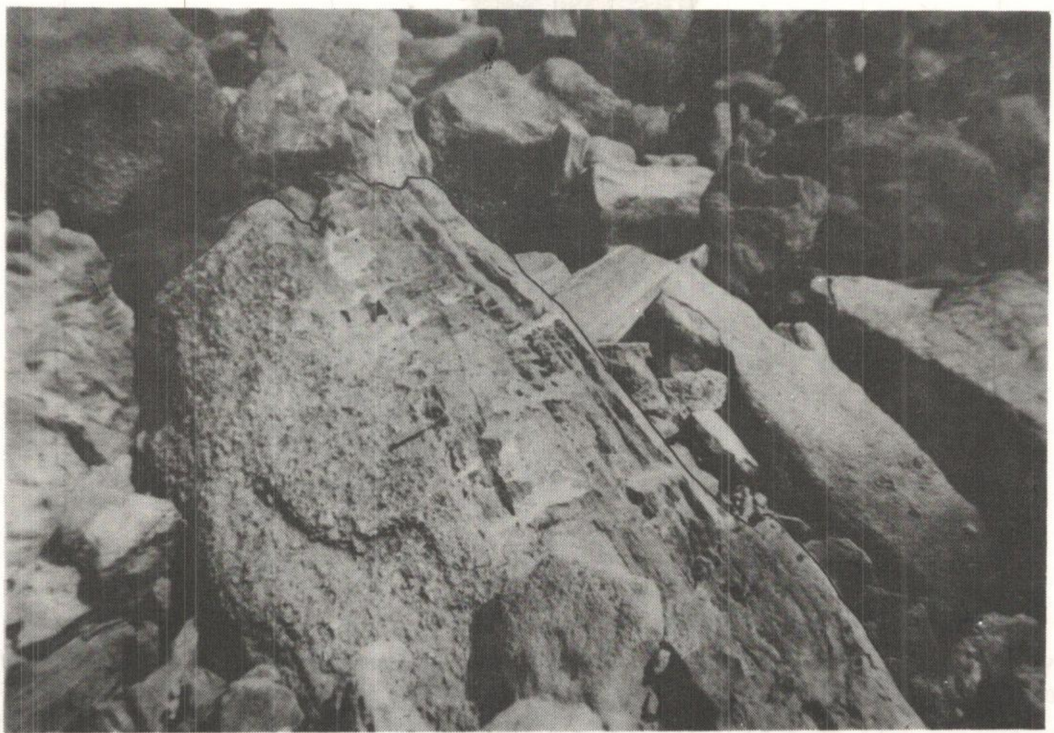

Fig. 5: Huge blocks of Ghachok formation along the flow course of Seti river.

MITIGATIVE MEASURES

Hazards can be mitigated by proper identification and the preparedness against its occurrence. Some of the mitigative measures for the geological hazards in the Pokhara Valley are suggested.

Debris flow hazard mitigation

For the mitigation of the debris flow hazard in the Pokhara Valley following things should be done:

- Identification of the debris source in the upper reaches of the Seti River,
- Determination of the recurrence of the debris flow by dating the previous debris flow events,
- Development of awareness to the public about probable hazard, and
- Delineation of the probable area to be affected by the forthcoming event.

Karstification hazard mitigation

Karstification in the Pokhara Valley is restricted to the calcareous sedimentary deposit accumulated in the valley during various events of debris flow. To mitigate the karstification hazard the following recommendations are proposed:

- Delineation of the area occupied by calcareous sediments,
- Identification of karstified and non-karstified area using geological and geophysical exploratory methods,
- Development of awareness to the public about the hazards posed by karstification,
- Improvement in the techniques of civil construction, and
- Lining of the sewerage and other drainage structures.

Landslide hazard mitigation

For the mitigation of the landslides along the bankslopes of the Seti River and its major tributaries following measures are suggested:

- Delineation of the area prone to landslide,
- Development of awareness to the public about the landslide hazard along the river bank edges,
- Restriction of the construction activity in the area prone to landslide hazard.

CONCLUSIONS AND RECOMMENDATIONS

The Pokhara Valley sediments are the results of large scale debris flow in the geological past. Realizing the repeated events of debris flow in the past, there is the possibility of occurrence of similar event.

It is possible to asses the scale and extension of the forthcoming debris flow by the careful study of earlier events and by identifying the suitability of the present environment for its occurrence. Although Pokhara Valley is covered throughout by calcareous clastic sediment susceptible to karstification but at present the field observation shows that the area underlain by the Ghachok Formation is more susceptible to karst development. The hazards due to bank collapse, block fall and topple along the banks of the Seti River and its tributaries are identified and the mitigative measures are recommended..

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