

Landslide hazard zonation map of Kurram Valley: A case study of landslide at Gharbina village, Parachinar, Kurram Valley

Asghar Ali¹, Khaista Rehman², Naveed Anjum¹ and Wajid Ali²

¹Department of Geology, University of Peshawar

²National Centre of Excellence in Geology, University of Peshawar

Abstract

Landslide hazard zonation map of Kurram valley shows that Gharbina village at Bulbulaq, Parachinar lies within the high landslide prone region. Geological investigations of the landslide/rotational slump and debris-flow at study area indicate that the inhabited property at Gharbina village is vulnerable to a devastating landslide. The total area of the slump that had badly affected wheat crops, orchards, poplar and walnut trees was approximately 19.6 hectare. It had also disrupted 118 meters dirt road, which connecting Gharbina, Khachan, Dand and Rajju villages to Parachinar city. Walls of the houses at Gharbina village are cracked and leaned. The affected area and the regions shown on landslide hazard zonation map of Kurram valley might be declared an area prone to landslide/slumping. The Gharbina village, which is badly affected during slump, should be permanently evacuated because the northward drift of the main scarp of the slump and southward movement along transverse fractures in the crown region may cause fatalities and infrastructure damages. Knowing the nature of the problem and the vulnerability of the area for slope failure, it is recommended that evacuation of the high hazard zone should be carried out as top priority to ensure safety of the inhabitants.

Keywords: Landslide hazard zonation; Slump; Gharbina village; Slope failure; Damages.

1. Introduction

Landslides are the downslope movement of unconsolidated regolith and weak bedrocks. It usually occurs in a region due to prolonged or intense torrential rainfall, snow fall, rock composition, steep topographic slopes, earthquakes and human activities (Brunsdon and Prior 1984; Tomkins et al., 2007). In catastrophic way landslides usually have effects on human lives, livestock, communication, productive land and infrastructures. However, careful landslide zonation indicating landslide prone slopes in a region can effectively minimize the total affect of landslide related hazards (Schuster and Krizek, 1978; Brunsdon and Prior, 1984; Varnes, 1984; Crozier, 1986; Carrara and Guzzetti, 1995). After establishing landslide hazard zonation for a region a detailed geological investigation of the entire area vulnerable to such type of hazards is vital to guide local population and engineers for long term solution.

Landslides are the most prevalent and devastating natural hazard across the Kurram

valley, Pakistan because it is characterized by active tectonics, steep slopes, landslide prone geological formations and active seismicity (Sato et al., 2007; Rehman et al., 2011). In Kurram valley majority of urban settlements are situated in landslide prone regions. This paper outline landslide hazard zonation using thematic maps (digital elevation model, slope and aspect) for entire Kurram valley and detailed case study of a landslide that occurred at Gharbina village on 18th April, 2012. The case study provides remarkable information on landslide events, which could potentially occur in future at landslide prone slopes across Kurram valley. It determines landslide nature and evaluation of the level of hazard (threats to human life and infrastructures).

2. Data layer preparation

Data layers were established using Digital Elevation Model (DEM) data of Kurram valley. The following data were used for the landslide hazard zonation.

2.1. Elevation

Elevation has been shown to affect slope stability in several ways. The susceptibility of a rock body varies with elevation i.e. at higher elevation rock bodies are usually highly weathered and have steep slopes as compared to intermediate and low elevation areas (Dai and Lee, 2002). Furthermore, the vegetation density and types may also vary with elevation. In this study the elevation profile of the area was divided in two categories, any area with elevation equal to or higher than 1500 m was assigned high risk factor (Fig. 1a).

2.2. Slope angle map

Slope stability highly depends on slope geometry (Huang and Li, 1992; Wu et al., 2001). Therefore, digital slope angle map of a region

plays fundamental role in landslide hazard zonation (Saha et al., 2002; Cevik and Topal 2003; Lee et al. 2004 a, b; Yalcin, 2008). Slope angle map was prepared for Kurram valley, using ASTER Digital Elevation Data (Fig. 1b). Most of the southern part of the valley has low slope $< 25^\circ$ while the northern part is characterized by high slope $> 25^\circ$. On the basis of slope the map was divided into five classes (Fig. 1b).

2.3. Slope aspect map

Slope aspect may have considerable influence on landslides initiation and occurrence. Moisture retention in soils on slopes, the amount of rainfall falling on the slope and vegetation development is related to slope orientation and angle (Wiezorek et al., 1997). Owing to the above mentioned factors landslides frequency may vary with slope orientation and angle (Fig. 1c, Dai and Lee, 2002).

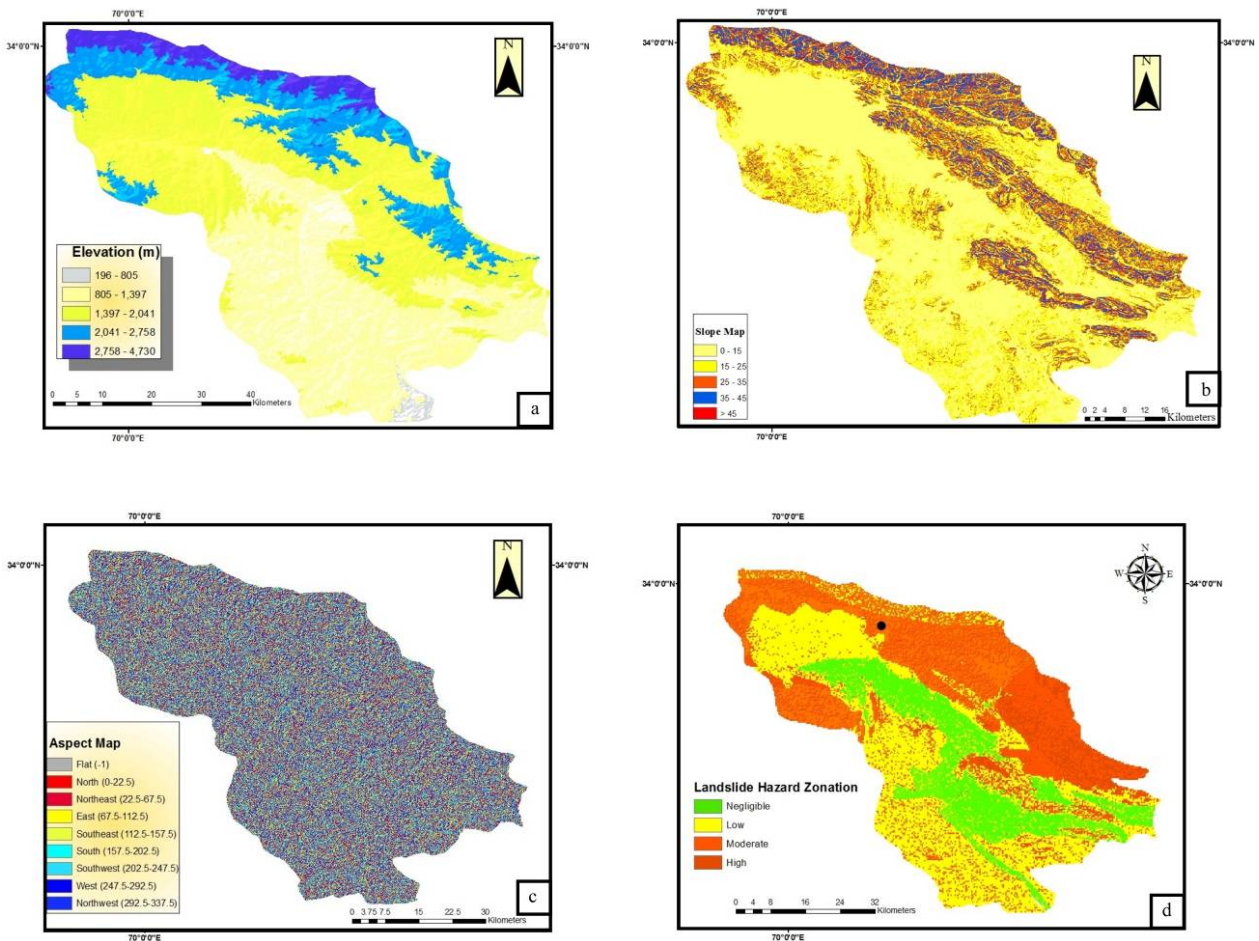


Fig. 1a) Digital elevation model of entire Kurram valley. (b) Slope map of Kurram valley. (c) Aspect map of Kurram valley. (d) Landslide hazard zonation of entire Kurram valley. Black circle showing case study area (Gharbina village).

2.4. Landslide hazard zonation map

Detail landslide hazard zonation map of Kurram valley was prepared by combining the data from layers mentioned above (Fig. 1d). The valley is classified into four classes named negligible, low, moderate and high hazard areas. According to final landslide hazard zonation, the case study area lies in the high risk region within the Kurram valley.

3. Case Study: The 18 April 2012 landslide at Gharbina village

3.1 Description of the event

On 18th April, 2012 ~195621m² rotational slump and debris-flow occurred at Gharbina village, Bulbulaq (Fig. 2), which is situated 8 km north-east of Parachinar city. Gharbina village is located between 33°54'46.16"N to 33°55'4.66"N latitude and 70°11'32.24"E to 70°11'53.17"E longitude with an average elevation between 2150 m to 1985 m (Fig. 1a).

The elevation difference between the crown and toe of the slump is approximately 563 m. The structural anatomy of the Gharbina slump consists of well-developed crown, scarp, bed rock, toe, slip plane and rubble. The main scarp shown in Figure 2, has the maximum width at the foot point of the scarp, where the debris are maximum and decreases further towards the exposed bedrock. The main movement of the slumped block is towards south, while the block has been rotated northward. The slumped block has been divided into numerous sub scarps, which expose bedrocks within the block. The vertical length of the scarps is gradually decreases towards south. The rotational slump has been taken place along a clay-bed slope, which is concealed by regolith derived from the surrounding mountains. The event had badly affected wheat crops, orchards, poplar and walnut trees, which were the only living, sources of income in the region (Fig. 3a-d). It had also disrupted 118 m road connecting Gharbina, Khachan, Dand and Rajju villages to Parachinar city (Fig. 3e). Walls of the houses at Gharbina village were cracked, which have potential for future hazards (Fig. 3f).

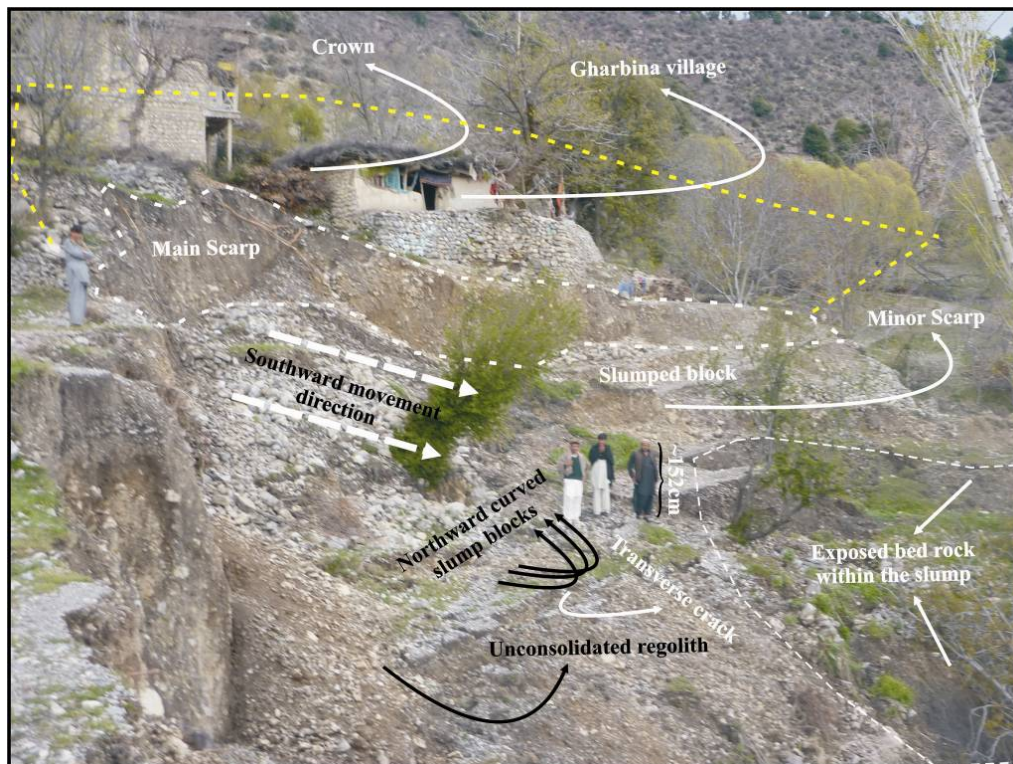


Fig. 2. Photograph showing main scarp of the Gharbina slump, which is ~ 0.5 meter from residential area. Key morphological features of the slump are shown on the photograph.

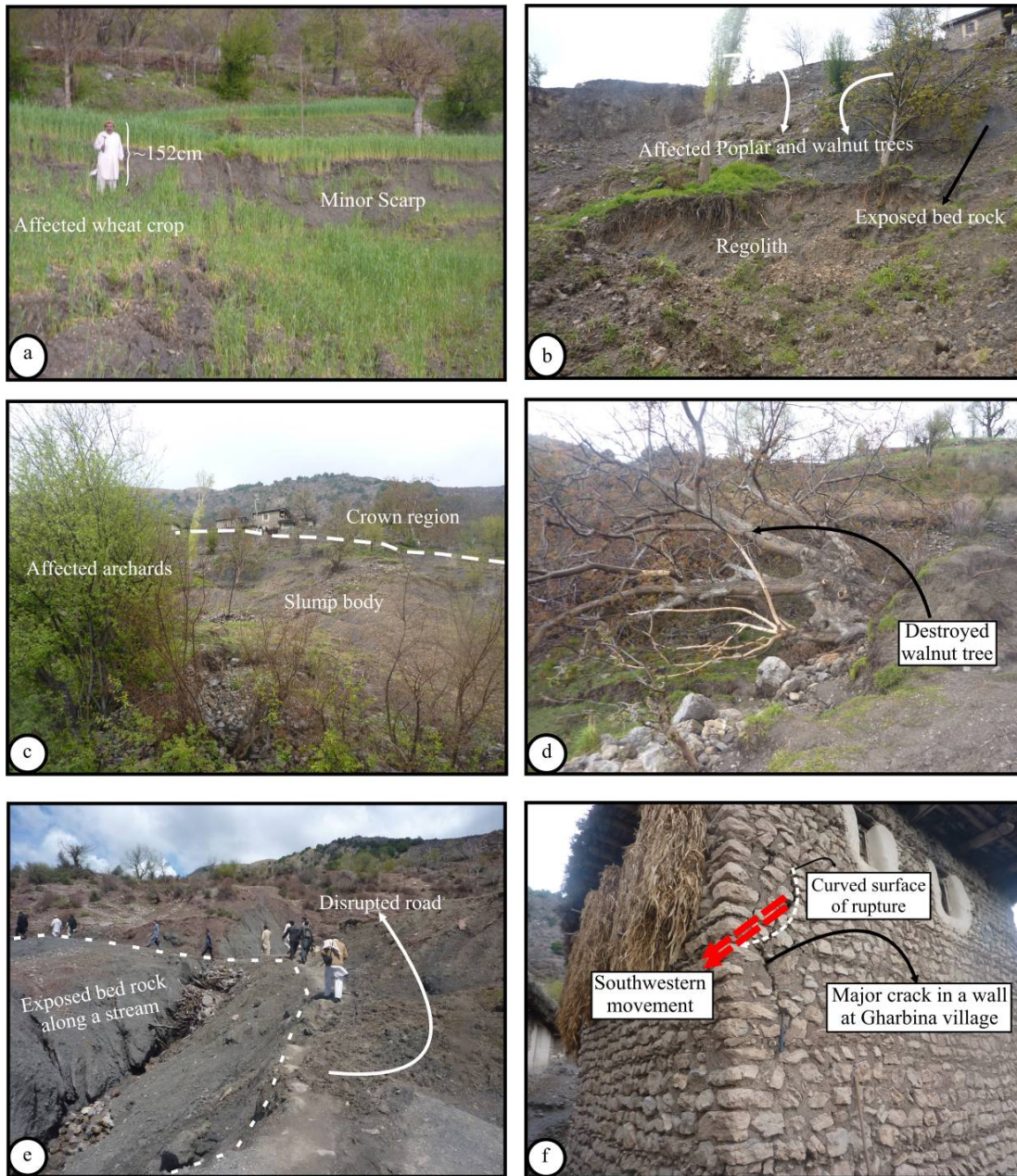


Fig. 3. Photographs showing slump induced destruction at Gharbina village, (a) Part of wheat crop affected during the slump, (b) Backward rotated poplar and walnut trees, (c) Destroyed and uprooted orchard, (d) Entirely uprooted walnut tree, (e) Destroyed community made road. It is the only road in the region, which connects Parachinar city with Gharbina, Khachan, Dand and Rajju villages and (f) Photograph showing cracks within the wall, which is leaned towards southwest at Gharbina Village. These cracks are synchronously developed during the slumping event in the area.

The village is constructed on unconsolidated regolith and underlain by thinly laminated grayish color shale and clay beds of the Cretaceous Kurram Formation/group. These beds are incompetent and highly susceptible to erosion through out the valley. Numerous active slope failures were observed in these clay beds across the region apart from the main

Gharbina event (Fig. 4a). The downslope direction of landslides/slumps in the region is dominantly controlled by Gharbina meandering stream. Both sides of the stream are prone to active landslide sites for example showing a minor scarp, mud house constructed in stream bed and a village on landslide prone slope (Fig. 4b).

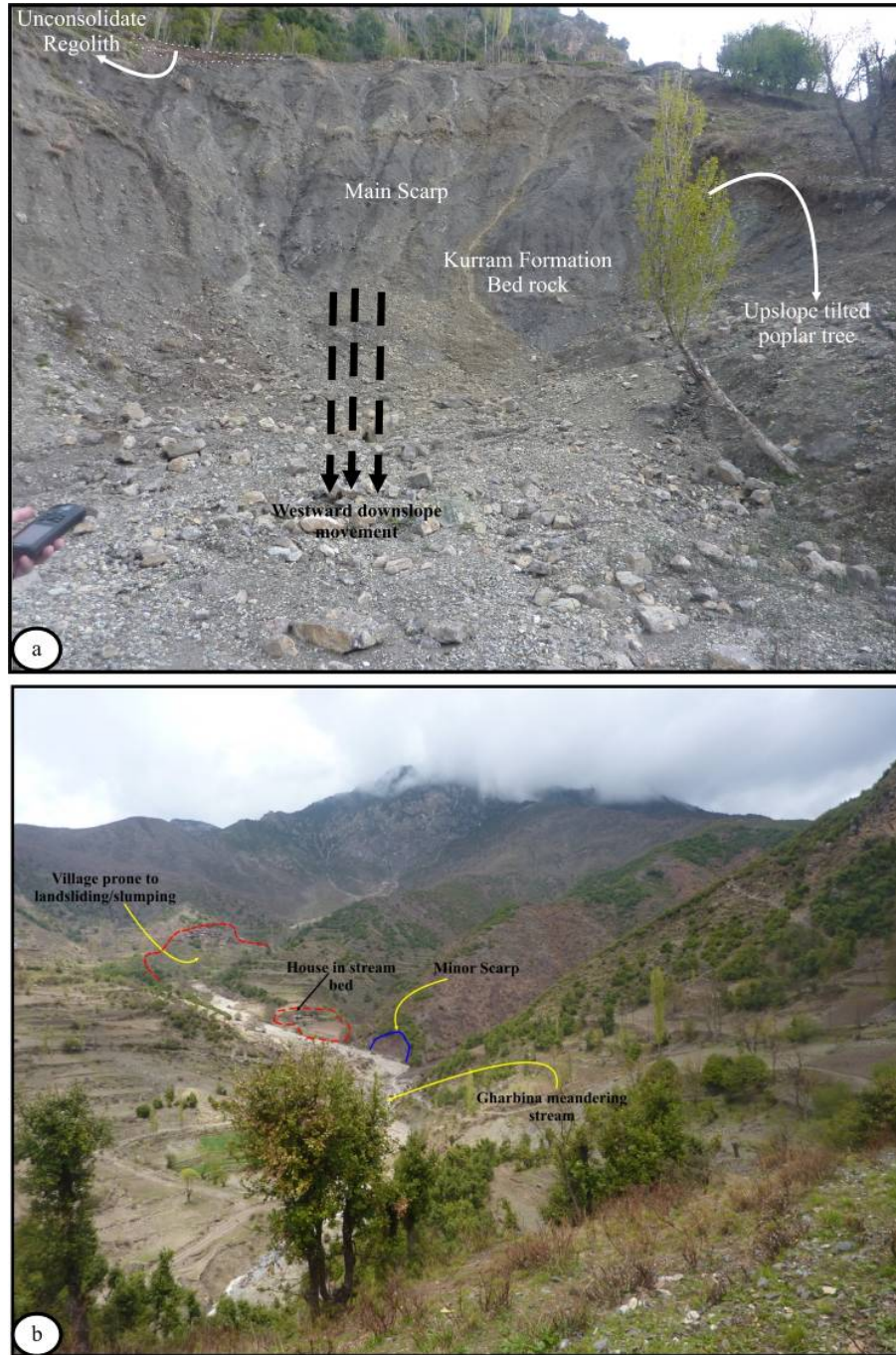


Fig. 4a) Photograph showing incompetent beds of the Kurram Formation/group susceptible to erosion and mass wasting across the region and (b) Photograph showing meandering nature of the Gharbina stream.

Personal communication with local community indicate that: (a) three houses were damaged by a landslide of the same intensity 40 years ago, (b) high rate of precipitation (torrential rain fall and snow) in the area for the last two years and (c) the whole area and particularly the slopes are characterized by numerous springs. Fortunately this

event did not cause any life casualties and injuries so far. A total of 255 people, consisting of 42 families have been residing the affected area in the crown region of the slump. Water-absorption related mass movement is evident in the area in the form of soil creep marked by tilted trees and electric poles (Fig. 5a,b).

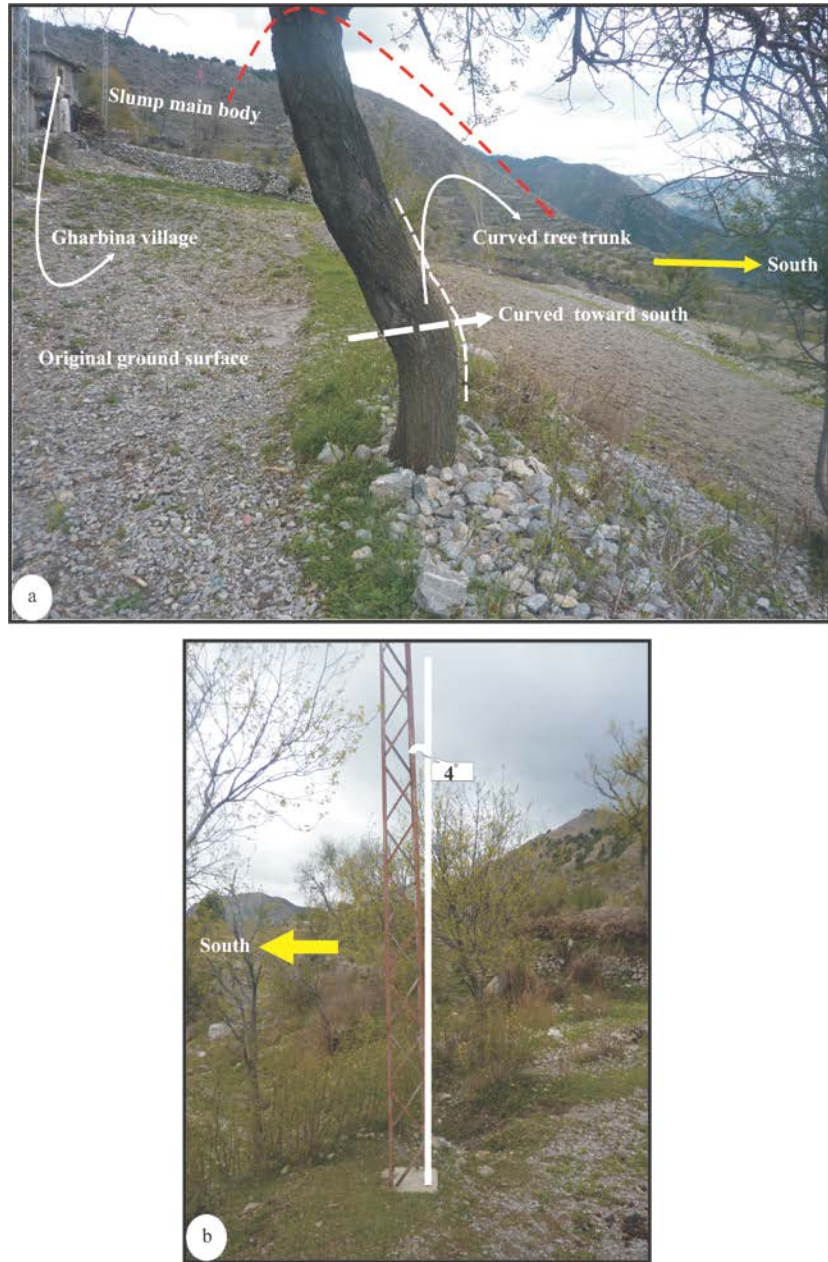


Fig. 5. Photographs showing south verging pronounced curves: (a) in a tree trunk and (b) life line, that formed in response to soil creep in the area. Note the creep preceded the slump in the affected area.

4. Regional geology

The age of exposed rocks in Parachinar, Kurram valley are mostly Cambrian, Jurassic and Cretaceous (Butt, 1988). These rocks exposed from north to south in the following stratigraphic sequence (Meissner et al., 1975):

- (i) Cambrian Migmatites, Gneissic granite and metasediments.

- (ii) Jurassic Samana Suk and Datta Formations.
- (iii) Cretaceous Kurram, Lumshiwai, Chichali Formations.

The Cretaceous Kurram Formation/group, which is exposed at Bulbulaq, borders the Jurassic Samana Suk Formation to north and the Quaternary Parachinar sediments to south (Fig. 11). The Kurram Formation/group consists of

reddish and greyish to greenish shale, mudstone, siltstone and clays. These interbedded lithologies contain thinly bedded limestone. The rocks of the Formation/group are overlain by a thick sequence of the Quaternary unconsolidated regolith that consists of sediments derived from the Jurassic Formations and residual soil. The reddish and dark greenish color of the soil indicates that the residual soil is derived from the weathering of the underlying thinly layered bedrocks. The clasts are predominantly angular, poorly sorted and unconsolidated. The Kurram Formation/group is intensely folded and faulted (Meissner et al., 1975).

5. Geological investigations

The conventional geological mapping techniques aided by enhanced image analyses of the satellite images are used for constructing the geological map of the affected area. The map is

based on the field classification of lithologies (Fig. 6).

The slumped body is characterized by abundant transverse cracks (Fig. 7a). Trends of these cracks were measured throughout the slumped block (Table 1). They are characterized by irregular surfaces and southward movement. Trends of these cracks were plotted on equal area rose diagram (Fig. 7b). The transverse cracks are east-west trending in the middle part of the slump. However, along the western and eastern walls of the slump the cracks are trending north-south (Fig. 8). These cracks show eastward movement along the western wall and vice versa. The movement due to N-S trending cracks on eastern and western walls is converging toward the main slumped block. The N-S trending cracks at converging point show prominent scarps. Subsequently the main western and eastern walls are characterized by main scarps.

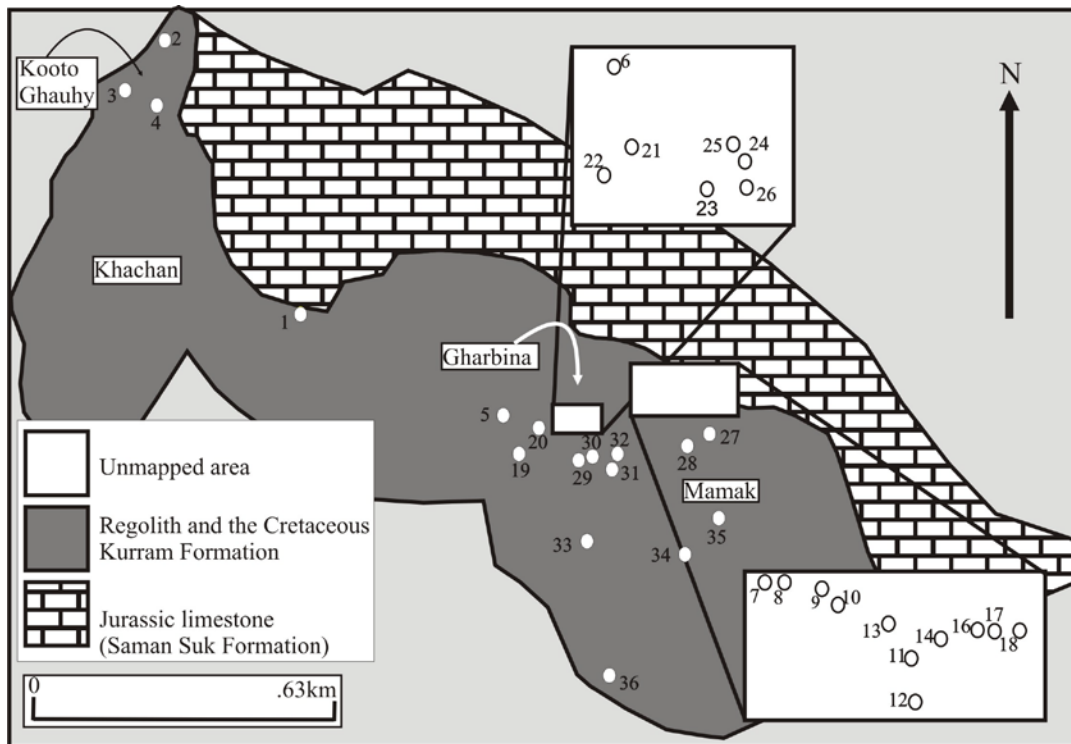


Fig. 6. Simplified geological map of the study area. White circles showing location of study stations.

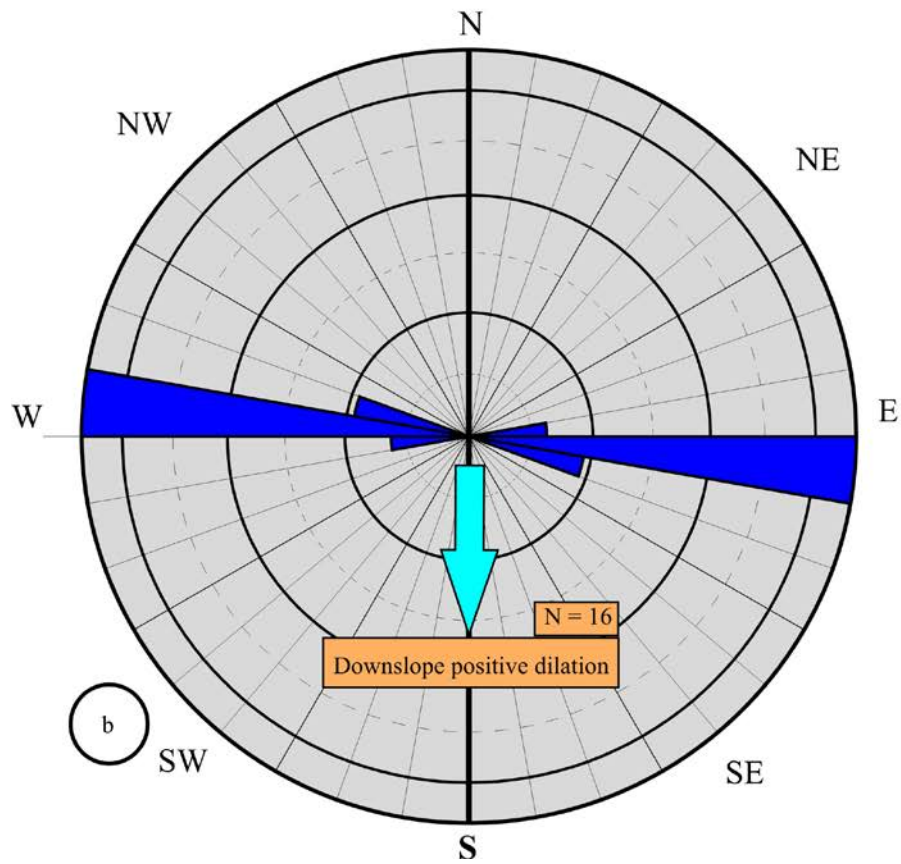


Fig. 7(a) East-West trending transverse cracks measured within the slump and (b) Equal area rose diagram showing trends of the transverse cracks in the slumped body.

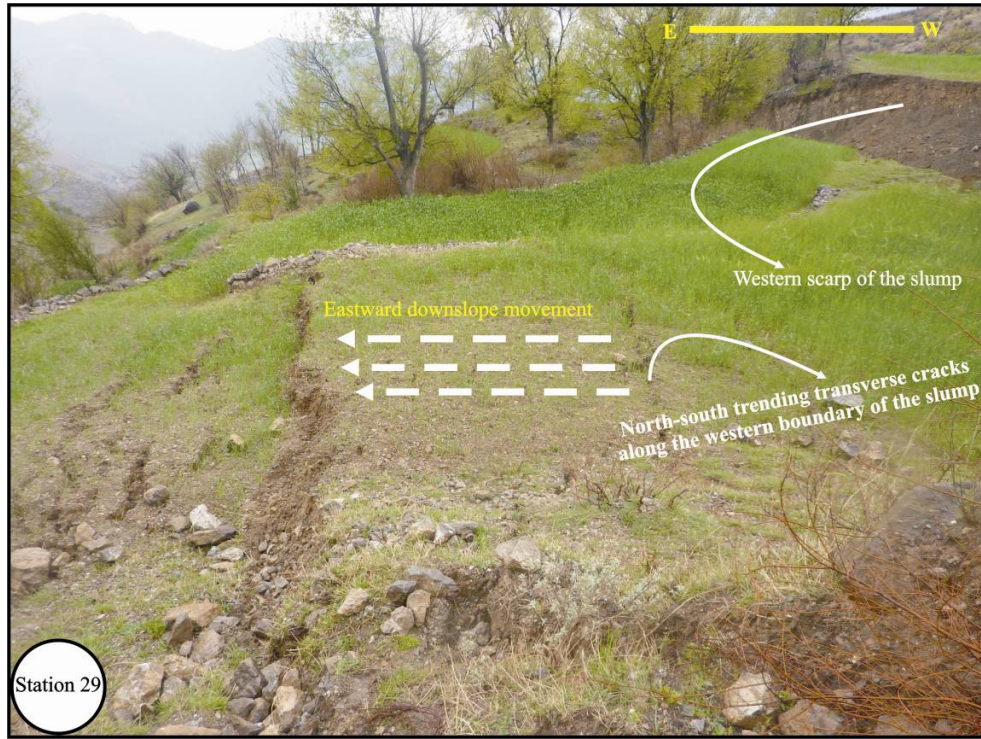


Fig. 8. Photograph showing north-south trending transverse cracks along the western wall of the slump. Cracks along the eastern and western walls indicate westward and eastward movement respectively, enhancing downslope southward motion in the area.

Table 1. Trends of transverse cracks in the central part of the slumped body.

Stations	Northing	Easting	trends
22	33° 55' 2.4"	70° 11' 41.9"	280°
23	33° 55' 2.3"	70° 11' 42.7"	280°
24	33° 55' 2.5"	70° 11' 43"	280°
25	33° 55' 2.6"	70° 11' 42.9"	260°
			260°
28	33° 55' 1.3"	70° 11' 51.50"	270°
			270°
			270°
30	33° 55' 0.3"	70° 11' 43.3"	270°
			275°
			270°
			273°
31	33° 54' 59.6"	70° 11' 45.2"	272°
			270°
			271°
			274°

Slump scarps facing downslope direction are the vertical exposures of the transverse cracks (Fig. 2). Major and minor scarps in the area are predominantly east-west trending. The main scarp of the slump has about 8.3 feet height. These scarps are fresh and unvegetated. It is interpreted that they are very recently developed in the area.

Tension cracks in the crown region of the slump, are predominantly long and east-west

trending (Fig. 9a, Table 2). Trend of these cracks are shown on equal area rose diagram (Fig. 9b). They were observed up-to 300 meters in the north direction of the major scarp. Trend of these cracks become north-south along the eastern and western extremities of the crown. N-S and E-W trending cracks were also observed within the walls of the inhabited area, which seems to be quite dangerous and alarming.

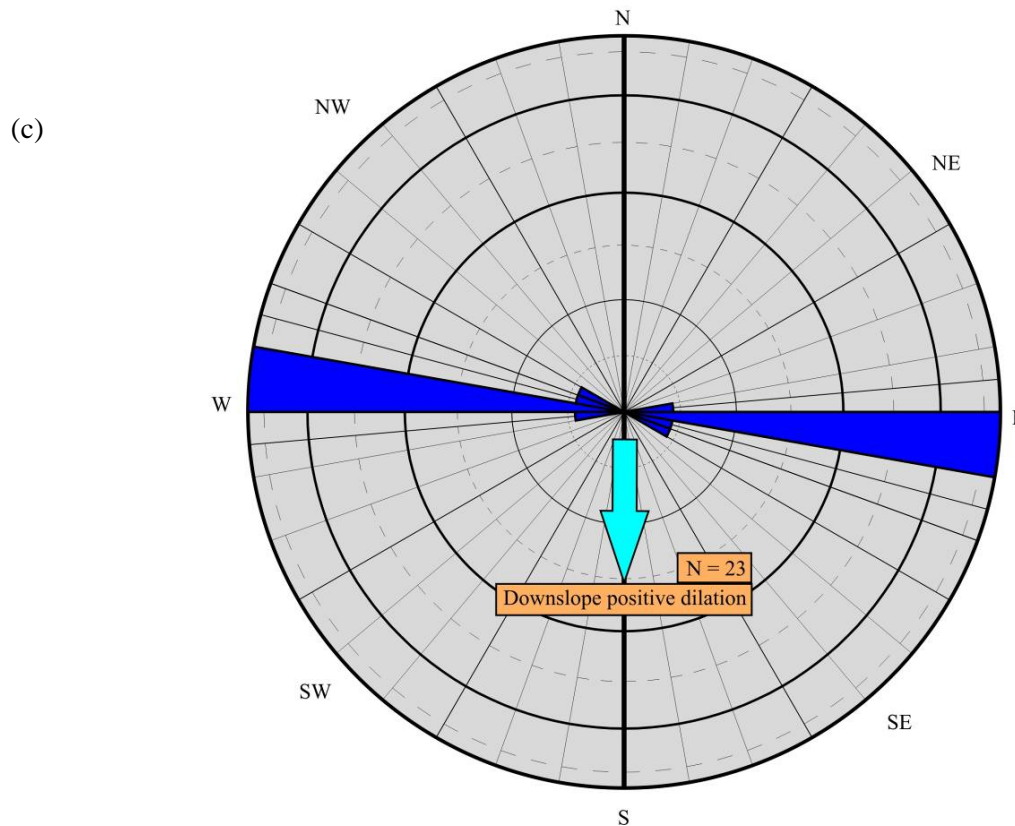
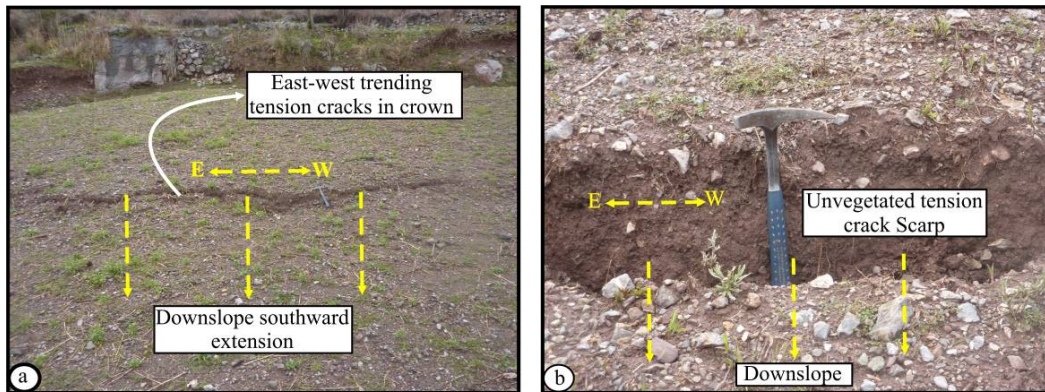


Fig. 9(a) East-West trending tension crack within the crown, (b) This photo indicates the downslope movement and depth of the tension crack. The arrows showing southward downslope motion of the ground and (c) Equal area rose diagram showing the trends of the tension cracks in the crown.

Table 2. Trends of tension cracks in the Crown region.

Stations	Northing	Easting	trends
5	33° 55' 2.8"	70° 11' 36"	270° 272° 270° 273°
7	33° 55' 5.6"	70° 11' 48.5"	270° 273° 271°
8	33° 55' 5.6"	70° 11' 48.9"	270° 270°
9	33° 55' 5.5"	70° 11' 49.6"	275° 270° 270° 271° 270°
10	33° 55' 5.3"	70° 11' 50"	272°
11	33° 55' 4.4"	70° 11' 51.3"	290°
12	33° 55' 3.7"	70° 11' 51.4"	265° 265°
14	33° 55' 4.7"	70° 11' 51.8"	280°
15	33° 55' 04.0"	70° 11' 52"	270°
16	33° 55' 4.8"	70° 11' 52.5"	285°
17	33° 55' 4.8"	70° 11' 52.8"	290° 270°

Oriented photographs were taken from curved tree trunks, tilted electric poles, transverse cracks, main and minor scarps, crown, tension cracks, backward rotated trees and sag ponds. Both younger and older trees in the crown part of the slump have pronounced downslope effects. It strongly indicates that the current rotational slump predated by an imperceptible creep. On the other hand the trees within the slumped block are inclined upslope. Sag ponds between the scarps and northward curved slumped blocks imply rotation of the dislocated blocks during the slumping (Fig. 10 a,b).

6. Conclusions

Landslide hazard zonation map was prepared to divide the Kurram valley into four zones showing negligible, low, moderate and high risk hazardous regions (Fig.1d). Landslide hazard

zonation map can be used for landslide assessment, appropriate mitigation, planning purposes and geotechnical control measures, which otherwise could cause serious fatalities and devastation to infrastructure across the Kurram valley.

Detailed geological investigations at Gharbina village, which lies within the high risk zone (Fig. 1d) indicate that the inhabited property is vulnerable to further slumping. The village is bounded by the E-W trending and N-S opening transverse cracks in the south and north. E-W trending and N-S opening transverse fractures in the crown region of the slump indicates southward downslope movement and northward drift of the main scarp, which is ~ 0.5 meter away from the inhabited area. The fractures in the leaned walls of Gharbina village are unable to sustain any southward downslope movement in the slump affected region.

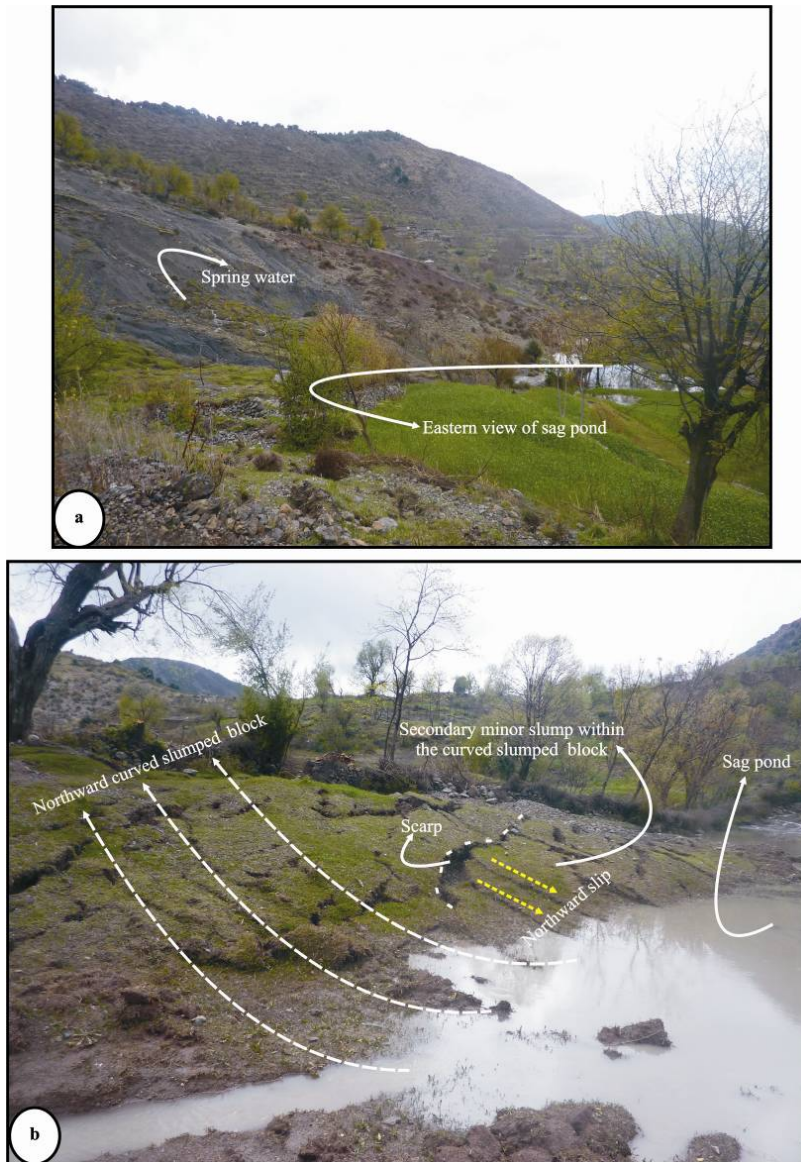


Fig. 10(a) Eastern view of the main sag pond and (b) Photograph showing sag pond, collecting rain and spring water. The northward motion of the slumped block is due to the curving rupture surface. Secondary slumps postdate the main slumping event.

The incompetent shale and clay beds of the Kurram Formation/group are highly susceptible to slumps and earth flow if they soak up water during heavy rains or snow falls. This was inferred because majority of slumping in the region are closely associated with these incompetent shale and clay beds of the Kurram Formation/group covered by unconsolidated regolith. Sag ponds, which are developed from the northward rotation of the leading edges of the slump materials within the main slump block, are filled with water from seepages and heavy rainfalls (Fig.10). The accumulation of water in sag ponds can exert

pressure on the confining walls, which can potentially accelerate down slope movement of the entire slumped block. The gap between the scarp and rotated slumped block in future can aggravate the situation by getting activated along the tension cracks in the crown and main slump regions after deep water percolation along these cracks (Fig. 9a, b). Southward downslope movement within the crown region has already been observed, which is alarming. The major cause of the slump and earth flow in the investigated area is because of water saturation in the regolith, Gharbina meandering stream and the underlying incompetent rocks of the

Kurram Formation/group. Apart from the Gharbina village, other active landslides in the region are closely associated with these unconsolidated and incompetent slope materials plus Gharbina meandering stream (Fig. 4b). Additionally this region is extremely susceptible to Landsliding because it endures heavy rains during summer and heavy snow falls during winter, which further adds enormous weight to slope materials. Highly landslide prone region in the vicinity of Gharbina village is shown in Figure 11. Apart from Gharbina villages other villages in the valley named Khachan, Dand and Rajju, which are built on unconsolidated regolith and thinly laminated shale and clay beds of the Kurram Formation/group, need further geological and engineering measures to assess and mitigate future landslides in the region.

Recommendations

1. The residential area, which is struck by slump, and has been evacuated, should be maintained as such till engineering measures are taken and the area is stabilized.
2. The tension cracks in the crown region and map slump should be sealed so that water from rain, irrigation and snow cannot infiltrate.

3. Watershed management of the drainage is crucial in the affected area as well as in the surrounding region. The crops fields on slopes should be provided with proper drainage system because infiltration of water from irrigation and rainfall could potentially reduce soil strength by pore-water pressure.
4. In the adjacent areas, which are not affected by landslide yet, precautionary measures should be announced to create public awareness (Figs. 4d; 11).
5. Any further excavation which might facilitate movement along slopes should be prohibited in the area shown in the Figure 11.
6. Forest cover is important in stabilizing slopes and protecting land from degradation. Therefore a campaign in the area against deforestation may be initiated to avoid incidents like this to happen in future.
7. The local residents should not disrupt the natural drainage pattern of the streams.
8. Surface water storages in the shape of ponds on slopes may be discouraged and monitored by community or administration.
9. Retaining walls at the toe of south and southwest dipping slopes (Fig. 11) can provide exceptional support to stop Gharbina meandering stream bank failure.

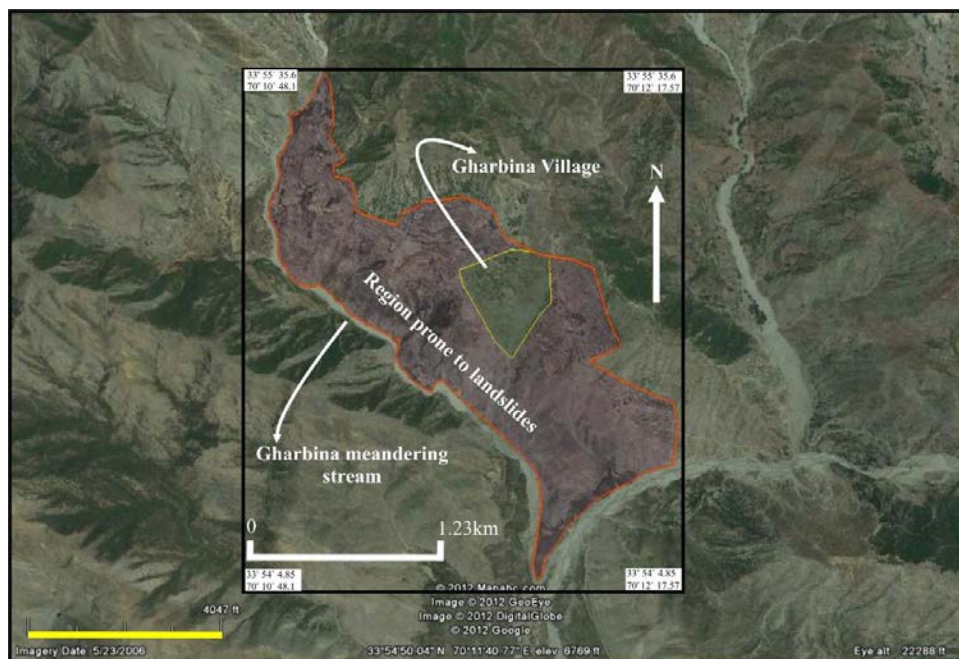


Fig. 11. Satellite map showing location of the region prone to future landslides. Note the landslide prone area is absolutely lacking forestation.

Acknowledgements

We thank Imran Wazir, FATA Disaster Management Authority (FDMA), Pakistan for providing logistic support during field work. We are thankful to local community of Gharbina village for providing historical and local information. We are thankful to the reviewers who provided very useful and valuable comments and their informative suggestions have helped in improving the manuscript.

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