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Role of clay minerals in the occurrence of landslides along Narayangarh-Mugling Highway section, central Nepal

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ABSTRACT

The Narayanghadh-Mugling highway section experiences numerous landslides and debris flows each year. In this study, soil samples from major landslides along the Narayangarh-Mugling highway section were investigated for clay mineral contents by using X-ray diffractometer to determine their role in the occurrence of landslides, if any. The X-ray analysis revealed illite, chlorite, and kaolinite as the main clay minerals in the soils. The comparison between landslide activity and clay mineral types suggests that landslides with soil containing illite as the dominant component are found more active than the landslide with little or no illite content in combination with chlorite and kaolinite. In addition to the geology, rainfall, land use changes, and some other human activities, the landslide activity in this section is also controlled by the presence of high swelling clay mineral illite along with the low swelling clay minerals chlorite and kaolinite.

Keywords: Narayagharh-Mugling section landslide , illite, chlorite, kaolinite

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INTRODUCTION

Geotectonically, the Himalayan range is a very dynamic region in the world. Due to its dynamic nature, the Himalaya experiences landslides and it is more frequent during monsoon season. Landslide is one of the principal processes of hill slope erosion, and it happens along most parts of the roads and highways in the Nepal Himalaya, and causes extensive loss of life and property. The temporal distribution of slope movements is largely determined by triggering factors such as rainfall, rapid snowmelt, volcanic eruption, earthquakes and human activities (Dai et al. 2002). Water in slopes causes a decrease in shear strength either by reducing the apparent soil cohesion or through the potential slip surfaces, a fact directly related to intense or long-lasting rainfall events (Gostelow 1991).

Landslide triggering threshold varies with the inherent stability of the terrain and therefore the spatial differences in the value of triggering thresholds can provide a relative measure of the geographic distribution of terrain susceptibility to landslide occurrence (Yalcin 2007). It is also clear that in some situations the triggering threshold for a given terrain is not constant but varies temporally as a result of landslide occurrence. As susceptible material is successively removed from hill slopes there is a residual strengthening of the terrain and the triggering threshold rises (Adhikari 2007). This phenomenon is referred to as 'event resistance'.

Study area

The Narayangarh-Mugling (NaMu) Highway is located in Chitwan District, central Nepal Himalaya at 110 km southwest from Kathmandu (Fig. 1). The study area spans the section of the Highway from Das Khola area (km 12.6) in the south to Bhirkunagaira area (km 28) in the north (Fig. 2). The study area is characterized by varied mountain topography.

Geologically, the NaMu section belongs to the Siwaliks and the Lesser Himalaya. The Lesser Himalayan rocks in the area include Kunchha Formation (light green phyllite, amphoblite) and Nourpul Formation (light grey phyllite and quartzite), and the rock in the Siwaliks are sandstone and conglomerate. The light grey phyllite and redish brown quartzite of Nourpul Formation were the dominant rock types observed in the study area (Fig. 2). Name of the rock formations and their lithology around the investigated area are summarized in Table 1.

The Main Boundary Thrust (MBT), a major thrust which separates the Siwaliks from the Lesser Himalaya passes through the lower part of the Das Khola and crosses the Highway close to km 14 (Fig. 2). Instabilities along the Das Khola, Khahare Khola and Jugedi Khola valleys are mostly located in the MBT zone and immediately north of it. Kamalpur Thrust Fault (KTF), Simaltal Thrust Fault

Table 1: Tabulated result of the geology and clay mineral contents to the respective samples

Sample Location	Name of Landslide	Geological Formation	Lithology	Clay Minerals
BS 17	Virkuna Gaira	Nourpul Formation	Light grey phyllite	illite, chlorite
BS 5	Kamere Khola	Noupul Formation	Milky White Feldspar with phyllite	iIllite, kaolinite, chlorite
BS 9	Bangesal Area	Nourpul Formation	Light grey phyllite	illite, chlorite
BS 15	Dumrebesi Khola	Nourpul Formation	Light grey phyllite with feldspar	kaolinite, chlorite
BS 16			Light grey phyllite	illite, chlorite
BS 1	Sindhure Khola	Nourpul Formation	Light grey phyllite with quartzite	illite,kaolinite, chlorite
BS 26	Kerabari Khola	Kunchha Formation	Light green amphoblite	kaolinite, chlorite
BS 27				
BS 24	Gaighat Khola	Nourpul Formation	Light grey phyllite with feldspar	illite, kaolinite, chlorite
BS 12	Das Khola	Siwalik Zone	Black in coloured	illite, chlorite, illite.

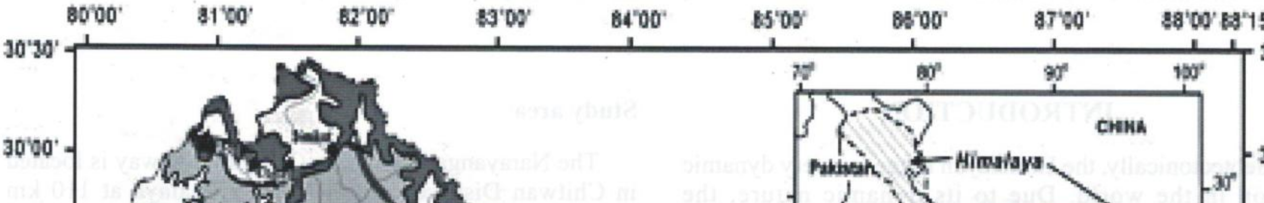

Fig. 1: Location map of the study area (modified after Hagen 1969, Upreti 1999 and Dahal and Hasegawa 2008)

(STF), and Virkuna Thrust Fault (VTF) are some local thrust faults in the area (Adhakari 2007) (Fig. 2), and large numbers of landslides are located in the vicinity of these local thrust faults. The KTF, STF, and VTF cross the highway at Km 16+700, Km 23+00, and Km 27+600, respectively (Fig. 2).

Scope of study

Weathering is a very important factor in landslide occurrences because it decreases the resistance of rock mass. Clay, a weathering product of rock mass, contributes to landslide occurrence due to their chemical and physical properties (Yalcin 2007). Clay minerals tend to form

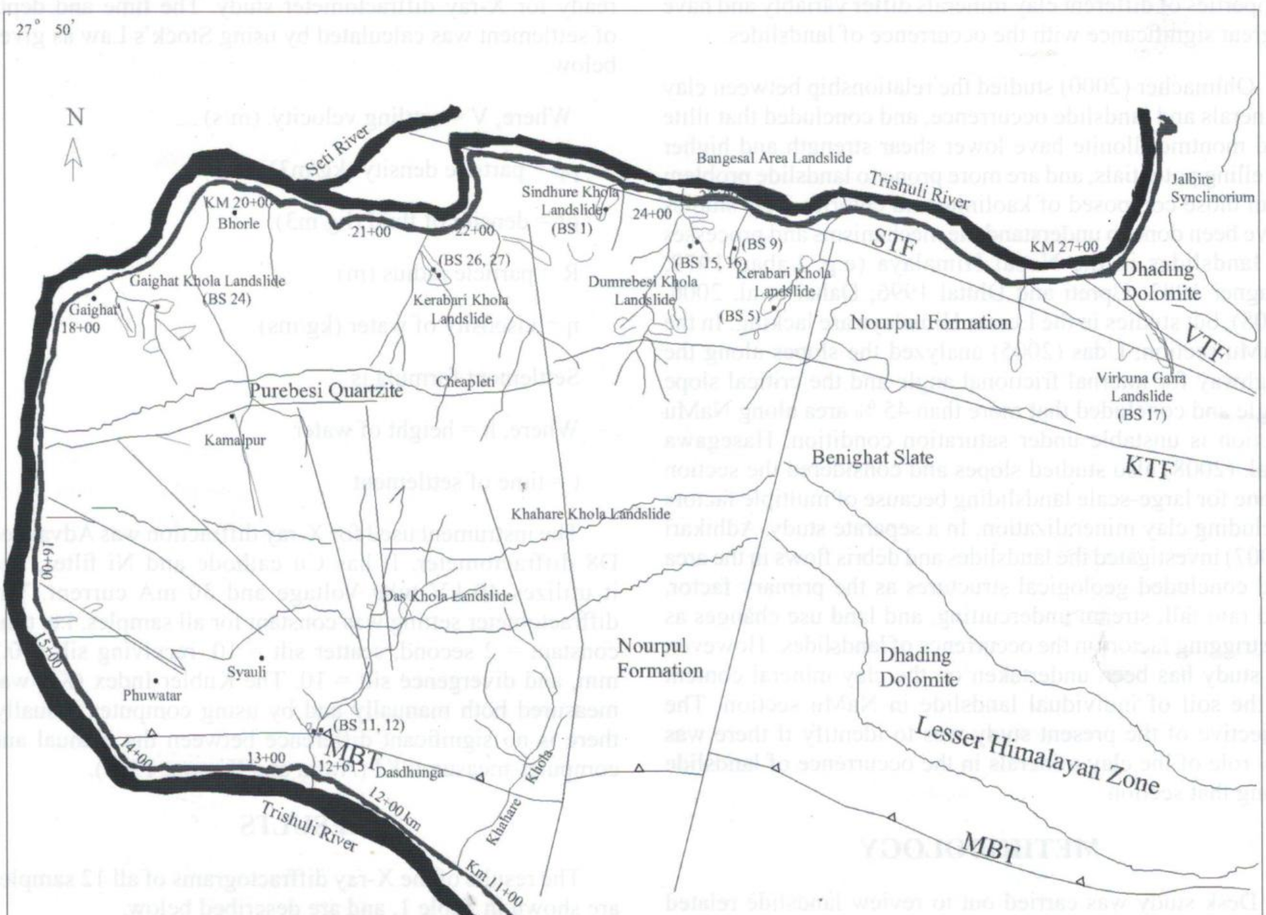

Fig. 2: Distribution of landslides, faults, and thrust faults in the Narayangarh-Mugling section (After Adhikari, 2007)

microscopic to sub microscopic crystals. They can absorb water or lose water from simple humidity changes. When mixed with limited amounts of water, clays become plastic and are able to be molded. When water is absorbed, clays will often expand as the water fills the spaces between the stacked silicate layers. The specific gravity of clays is highly variable and is lowered with increased water content (Lee and Min 2001; Frattini et al. 2004). The shear strength and the swelling properties of different clay minerals differ variably and have a great significance with the occurrence of landslides.

Ohlmacher (2000) studied the relationship between clay minerals and landslide occurrence, and concluded that illite and montmorillonite have lower shear strength and higher swelling potentials, and are more prone to landslide problem than those composed of kaolinite and chlorite. Few studies have been done to understand the mechanisms and processes of landslides in the Nepal Himalaya (e.g. Laban 1979; Wagner 1983; Upreti and Dhital 1996; Dahal et al. 2006, 2008), but studies in the Lesser Himalaya are lacking. In the NaMu section, Udas (2005) analyzed the slopes along the Highway for internal frictional angle and the critical slope angle and concluded that more than 45 % area along NaMu section is unstable under saturation condition. Hasegawa et al. (2008) also studied slopes and considered the section prone for large-scale landsliding because of multiple factors including clay mineralization. In a separate study, Adhikari (2007) investigated the landslides and debris flows in the area and concluded geological structures as the primary factor, and rain fall, stream undercutting, and land use changes as the trigging factors in the occurrence of landslides. However, no study has been undertaken on the clay mineral content in the soil of individual landslide in NaMu section. The objective of the present study was to identify if there was any role of the clay minerals in the occurrence of landslide along that section.

METHODOLOGY

Desk study was carried out to review landslide related previous works in the NaMu section. Following the desk study, a field investigation was undertaken to identify and locate active landslides along the highway and mountain slopes in different parts of the study area. Geological data were collected, and landslide mapping was performed with the measurement of landslide dimensions. Twelve soil samples were collected, 11 from active landslides and one from stable area, for clay mineral analysis.

The soil samples were analyzed for clay mineral content in the laboratory of the Central Department of Geology, Tribhuvan University. First, grain size analysis of the soil samples was performed by using dry sieving method to remove the particles >75 μm. The samples obtained from the sieve analysis were then put into the hydrometer for 8.54 hours in 8 cm water column and 11 hours if the water column is 10 cm.

Soil particles (< 2 μm) suspended in water column after sedimentation were removed with the help of pipe and collected in different jugs. After 30 minutes, the water was removed from the jugs and the samples settled at the bottom were collected and centrifuged with a spin of 1300 rpm. The centrifuged samples were taken out and placed on a glass slide with the help of a pipette, covering an area with 1 cm diameter. The sample was allowed to dry overnight and was ready for X-ray diffractometer study. The time and depth of settlement was calculated by using Stock's Law as given below.

Where, V = settling velocity. (m/s)

ρp = particle density (kg/m3)

ρf = density of fluid (kg/m3)

R = particle radius (m)

η = viscosity of water (kg/ms)

Settlement formula is

Where, h = height of water

t = time of settlement

The instrument used for X-ray diffraction was Advanced D8 diffractometer. It has Cu cathode and Ni filter, and it utilizes 40 kV tube Voltage and 30 mA current. The diffractometer setting was constant for all samples, i.e. time constant = 2 second, scatter silt = 10, receiving silt = 0.2 mm, and divergence silt = 10. The Kubler Index (KI) was measured both manually and by using computer. Usually, there is no significant difference between the manual and computer-measured KI (Awan and Kimura 1996).

RESULTS

The results of the X-ray diffractograms of all 12 samples are shown in Table 1, and are described below.

Virkunagaira area (km 26 - km 28)

Most of the landslides in the Virkunagaira area were retrogrative in nature, and the landslide sampled for X-ray analysis was measured 30 m long, 12 m wide and 3 m deep (Figs 2 and 3a). The rock type around the landslide was moderately weathered light grey phyllite of the Nourpul Formation. The VTF passes through this area (Fig. 2). The X-Ray diffractogram of the soil sample (BS 17) from this landslide contained illite peak at 2theta = 8.8, chlorite at 2theta = 12.6, and again illite at 2theta = 17.7 (Fig. 3b).

Kamere Khola (km 24+740)

The landslide at Kamere Khola was 60 m long, 30 m wide and 5 m deep (Fig. 2). Rocks exposed in the area were intercalation of milky white quartzite and light gray phyllite of the Nourpul Formation. They were moderately weathered.

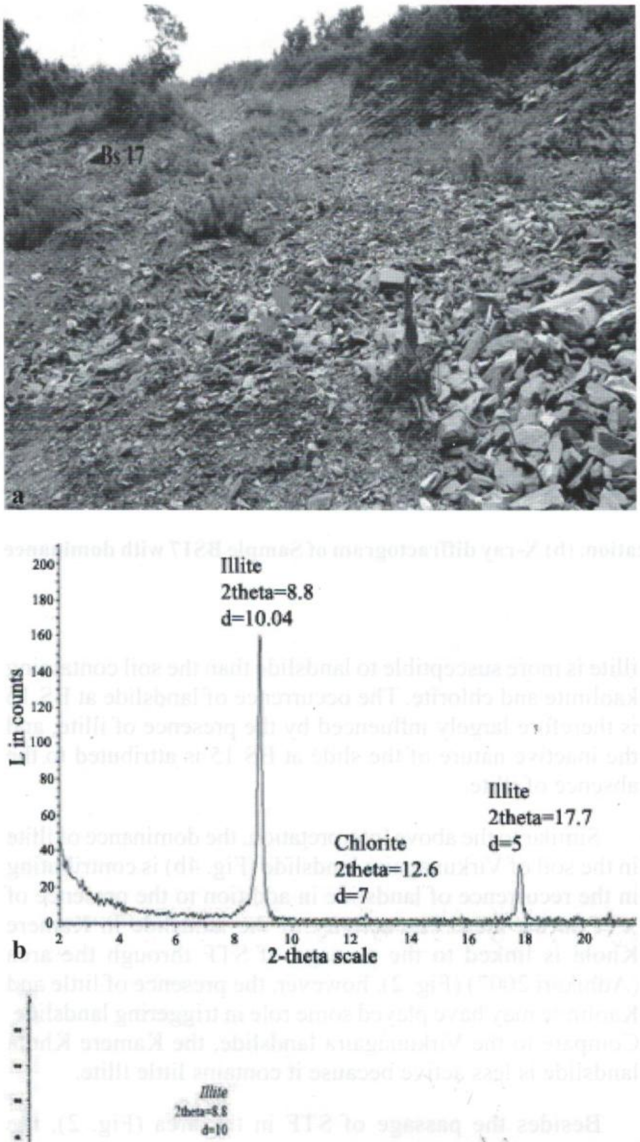

Fig. 3: Dumrebesi Khola Landslide: (a) Photograph with location of inactive and active parts, (b) X-ray diffractogram of sample BS 15 and, (c) X-ray diffractogram of sample BS 16. The samples BS 15 and BS 16 show the dominance of chlorite and illite, respectively. Landslide location is shown in Fig. 2.

The STF passes through the area (Fig. 2).The overall nature of the material produced by the landslide was bouldery, and it had small or no flowing components. The X-ray analysis of the soil sample (BS 5) taken from the Kamere Khola landslide showed the presence of chlorite peak at 2theta = 6.3, illite peak at 2theta = 8.8, kaolinite peak at 2theta = 12.4, and again chlorite at 2theta = 18.9.

Bangesal area (km 24+600)

The Babgesal landslide (Fig. 2) was 80 m long, 60 m wide, and about 5 m deep and the rocks in the area constituted of interbeded phyllite and quartzite with subordinate amount of slate of Nourpul Formation. Quartzite was dominant and highly crushed and weathered. The STF runs across the landslide (Fig. 2). The X-Ray analysis of the soil sample (BS 9) extracted from highly weathered quartzite zone showed peak of chlorite at 2theta = 6.3, illite at 2theta = 10.07, again chlorite at 2theta = 12.5 and unidentified minerals in different positions.

Dumrebesi Khola (km 24+300)

The landslide at Dumrebesi Khola was 155 m long, 60 m wide and 3 m deep (Fig. 2), and consisted of light gray phyllite of the Nourpul Formation. The landslide had both inactive and active parts (Fig. 3a) and the bedrocks (phyllite) in these two parts were slightly and moderately weathered, respectively. The landslide lies between the KTF and STF (Fig. 2). Two soil samples taken from the landslide, BS 15 from inactive part and BS 16 from the active part, revealed different clay mineral content. In the inactive part (BS 15), chlorite peak at 2theta = 6.3, kaolinite peak at 2theta = 12.4, and again chlorite peak at 2theta = 18.9 were observed (Fig. 3b). In the active part (BS 16) on the other hand, the X-ray revealed illite peak at 2theta = 18.8, chlorite at 2theta = 12.6 and again illite at 2theta = 17.7 (Fig. 3c).

Sindhure Khola (km 23)

The Landslide in Sindhure Khola was 110 m long, 40 m wide and 3 m deep, and was active even during winter, if rainy. The area was part of the Nourpul Formation and consisted of interbeded quartzite and phyllite, which were highly crushed and weathered. The STF passes across the landslide (Fig. 2). The X-Ray Diffractogram of soil sample (BS 1) from Sindhure Khola landslide displayed illite peak at 2theta = 8.8, chlorite peak at 2theta = 12.5, and again illite peak at 2theta = 17.8.

Kerabari Khola (km 21+560)

The rock unit around the Kerabari Khola area was the Kuncha Formation with highly weathered and deformed phyllite and slate in the basal part, an overlying body of amphibolite (metamorphosed basic igneous rock), and quartzite on the top. The amphibolite was highly fractured and dominated the lithology of the area, and the quartzite was slaby with 3-4 sets of joints. Rock fall and slides were the characteristic features of the area. The soil samples (BS 26

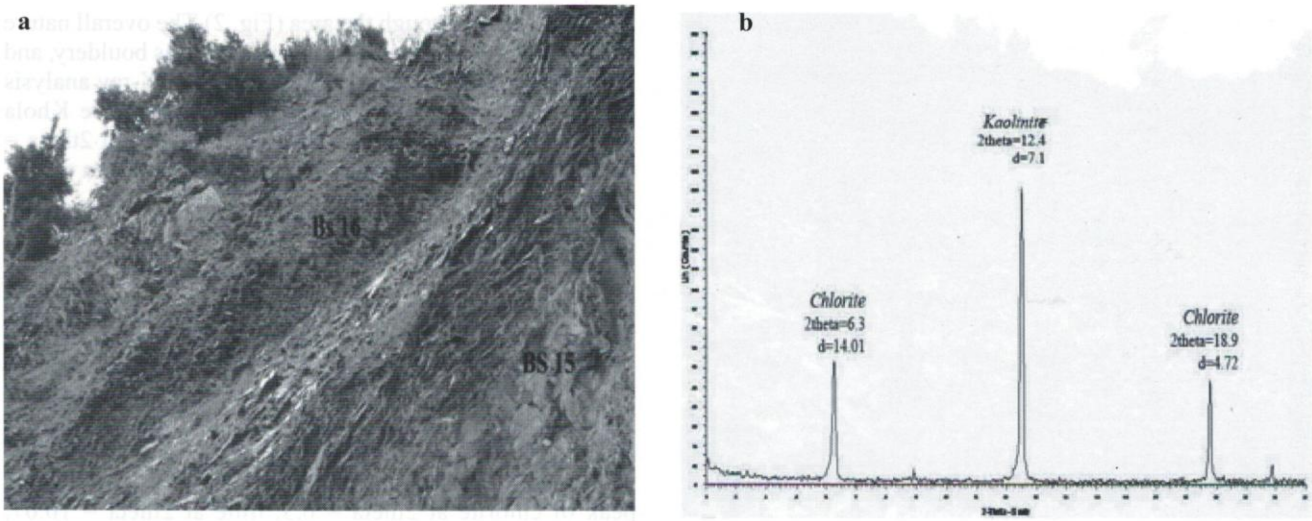

Fig. 4: Virkunagaira Landslide: (a) Photograph with soil sample location, (b) X-ray diffractogram of Sample BS17 with dominance of illite. Landslide location is shown in Fig. 2.

and BS 27) taken from the highly deformed and weathered phyllite showed chlorite at 2theta = 6.3, kaolinite at 2theta = 12.4 and again chlorite at 2theta = 18.9.

Gaighat Khola (km 18+450)

The Landslide at Gaighat Khola area (Fig. 2) was one of the most active landslides in the area. The rocks around the area were interbeded quartzite, phyllite, and slate of the Nourpul Formation. The quartzite was highly crushed into powder and the phyllite and slates were highly weathered. The STF runs across the landslide (Fig. 2). X-Ray diffractogram of the soil sample (BS 24) showed the presence of chlorite peak at 2theta = 6.3, illite at 2theta = 8.8, kaolinite at 2theta = 12.4, illite at 2theta = 17.8 and chlorite at 2theta = 18.9.

Das Khola Valley

The MBT in the upper reaches of the Das Khola (Fig. 2) marked a wide zone with intense jointing, fracturing, brecciation (dolomite, quartzite and slates), and presence of shearing features (Fig. 5a). The X-ray diffractogram of the fault gauge showed the presence of illite at 2theta = 8.8, chlorite at 2theta = 12.6, and again illite at 2theta = 17.7 (Fig. 5b).

DISCUSSIONS

In the landslide with the same geology and structures, the presence of kaolinite and chlorite with dominance of chlorite (Fig. 4b) in the inactive part, and the presence of chlorite and illite with dominance of illite (Fig. 4c) in the active part of the Dumrebesi landslide (Figs. 2 and 4a) provides a basis of comparison of the role of illite and chlorite. As illite has lower shear strength and higher swelling potential than chlorite and kaolinite (Ohlmachar 2000), soils containing illite is more susceptible to landslide than the soil containing kaolinite and chlorite. The occurrence of landslide at BS 16 is therefore largely influenced by the presence of illite, and the inactive nature of the slide at BS 15 is attributed to the absence of illite.

Similar to the above interpretation, the dominance of illite in the soil of Virkunagaira landslide (Fig. 4b) is contributing in the recurrence of landslide in addition to the presence of VTF in the area. The activity of the landslide in Kamere Khola is linked to the passage of STF through the area (Adhikari 2007) (Fig. 2), however, the presence of little and Kaolinite may have played some role in triggering landslide. Compare to the Virkunagaira landslide, the Kamere Khola landslide is less active because it contains little illite.

Besides the passage of STF in the area (Fig. 2), the presence of little illite in the soil of Bangasal landslide is considered as an additional factor for sliding to occur. In addition to the favorable geological condition for landslide activities in Sindhure Khola area due to the influence of STF, the presence of abundant illite in the soil is interpreted as the key factor for the sustained landslide activity.

The landslides in Kerabari Khola are largely controlled by rock discontinuities in amphibolites and quartzite. The inactivity of the landslide in the basal part, which consists weathered phyllite and slate, is the lack of high swelling clay mineral illite and presence of low swelling clay minerals chlorite and kaolinite in sample BS 26. Unlike other landslides discussed above, there is little influence of the local thrusts in Gaighat area (Fig. 2). The presence of illite, chlorite, and kaolinite with dominance of illite is interpreted as the reason behind the formidable activity of Gaighat landslide.

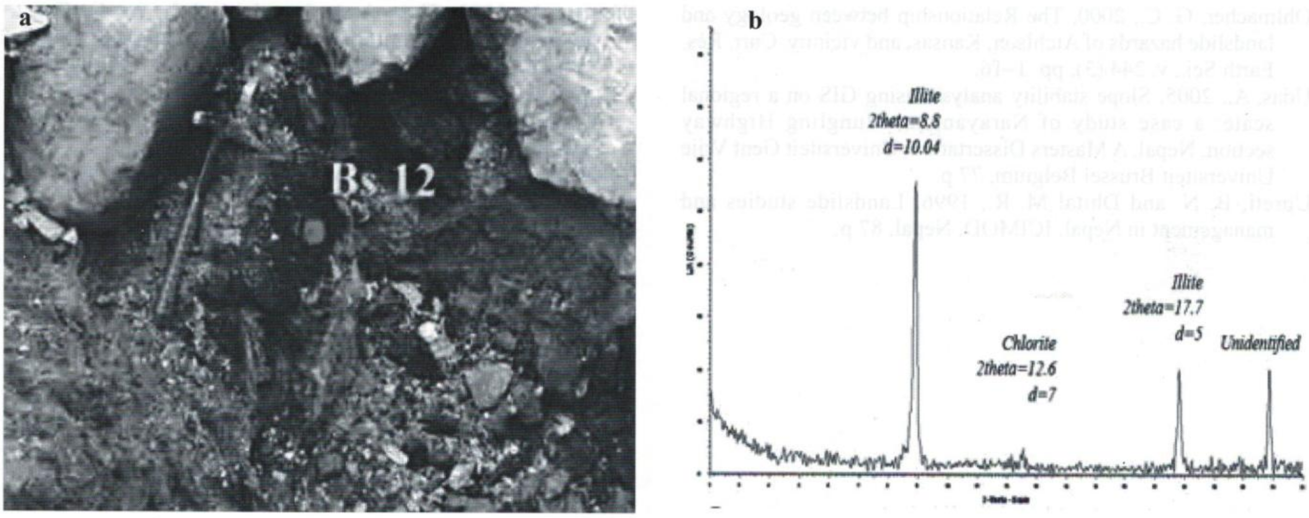

Fig. 5: Fault gauge in the MBT zone in Das Khola valley (a) Photograph with sample location, (b) X-ray diffractogram of sample BS12. Landslide location is shown in Fig. 2.

Though there was no landslide at the sampling site as it was stream bed (Fig. 5a), the presence of illite in the sample (BS 11) clearly indicates that MBT zone is not only susceptible to landslide because of tectonic activity but susceptible to failure due to the presence of clay mineral content, particularly illite.

CONCLUSIONS

The Narayangarh-Mugling highway section is prone to landslide. While geology and geological structures are known to be the main factors, rainfall, slope undercutting, land use changes, and other human activities are triggering factors. The present study also clearly reveals that the presence of high swelling clay mineral illite along with the low swelling clay minerals chlorite and kaolinite has played an important role in the occurrence and recurrence of landslides in the Narayangarh-Mugling highway section.

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