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An approach of geological mapping and geotechnical investigation: Case study from the Lalitpur Metropolitan City, Nepal

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ABSTRACT

Urbanization is rapidly growing throughout the world, especially in the least developed and developing countries necessitating proper land use planning. However, the lack of sufficient study has created the possibility of unprecedented geohazards. In this study, a detailed geological and engineering geological mapping along with the geotechnical analysis of soils and sediments from the Bhainsepati–Pharsidol area of Lalitpur District has been carried out. Detailed geological maps and geological cross-sections were prepared on the scale of 1:25,000 following the most adopted stratigraphy of central Nepal for both hard rocks and Quaternary deposits. Two mappable geological units like the Tistung Formation and the Chandragiri Limestone of the Phulchauki Group are found within the hard rock succession at the study area's hill sections. Similarly, the Quaternary succession is mapped into the Lukundol Formation and the Chapagaon Terrace deposits of Kathmandu Valley sediments from older to younger succession respectively. There is a distinct erosional unconformity between the rocks of the Phulchauki Group and the Quaternary Valley sediments. A kinematic analysis of discontinuities developed in the rocks was carried out in the rock slopes found in the area. Both field and laboratory analyses of soil samples were carried out for the representative samples. The laboratory tests include moisture content, specific gravity, particle size distribution, soil consistency, compaction, and consolidation properties. Finally, an engineering geological map was prepared on the same scale as geological mapping showing the details of the distribution of geo-materials. This study is expected to be valuable to make proper land-use decisions for town planning and developmental activities in the rapidly growing city of Nepal.

Keywords: Urban geology, geological mapping, geotechnical investigation, Lalitpur

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INTRODUCTION

Urban geological studies are necessary for underdeveloped countries like Nepal. The urban population around the world is rapidly increasing (Angel, 2012; Angel et al., 2005). Nearly 80 percent of developed countries' residents live in urban areas and developing countries are experiencing significant growth in urban population over the last two decades. The unprecedented rate of urbanization has created numerous problems in cities including overcrowding. Because of overcrowding, many cities already face the problem of unemployment, water scarcity, sanitation, health hazards, degradation of environmental quality, and development of slums (Flörke et al., 2018; Khanal et al., 2021a; Ooi and Phua, 2007; Vardoulakis et al., 2016). In addition, climate change is likely to aggravate certain urban health problems, the severity of extreme weather events, water scarcity, and disturbing urban ecology (Heal et al., 2013; Khanal et al., 2021b; Vardoulakis et al., 2014). To cope with this challenge of high urbanization many cities around the world are already expanding their boundaries into their periphery (Ahani and Dadashpoor, 2021; Dadashpoor and Malekzadeh, 2021). For proper land use planning and developmental activities, detailed studies of geology, and engineering geology are the prerequisites for any territory.

In Nepal, the Kathmandu Valley is experiencing an unprecedented rate of population growth which makes the valley one of the fastest-growing cities in population in the world. Due to this accelerated growth of population, the construction of buildings and other infrastructures for human settlement is also increasing rapidly. The land for cultivation is declining and areas for recreational purposes are also decreasing due to the increasing population. The environmental quality of the valley is on a speedy decline as can be seen from the high level of air pollution, water pollution, and land pollution in the urban areas. If appropriate infrastructures, housing, water supply, and other amenities cannot keep up with the rate of population growth then sustainability cannot be maintained. Keeping this in mind, the government of Nepal has posed interest in properly managed urbanization, named the smart cities. This demands a detailed geological and geotechnical study of those planned smart city areas.

Many geoscientific studies and investigations have been carried out in Kathmandu for decades by many researchers. Kathmandu basin is filled with thick semi-consolidated to well-consolidated fluvial-lacustrine sediments of the Neogene to Quaternary clay, silt, sand, and gravel (Moribayashi and Marau, 1980; Yoshida and Igarashi, 1984; Sakai, 2001) overlaying the rock successions of the Kathmandu nappe. Both the rock succession of the Precambrian Bhimphedi Group and the Paleozoic Phulchauki Group are well-distributed around the hills of the Kathmandu valley (Stöcklin and Bhattarai, 1977). The Quaternary sediments of the Kathmandu Valley have been studied by many researchers (Yoshida and Igarashi, 1984; Dongol, 1987; Sah et. al., 1997; Shrestha et al., 1998; Sakai, 2001; Acharya and Paudyal, 2018). Yoshida and Igarashi (1984) established three stratigraphic units for the valley sediments as the Lukundol Formation (Older stage deposits), (Pyangaon, Chapagoan, and Boregaon terrace deposits) as middle stage deposits, and the younger deposits (Gokarna, Thimi and Patan Formation). Sah (1995) divided the Quaternary sediments of the Kathmandu valley into seven different units and named the Tarebhir Conglomerate, Lukundol Formation, Sunakothi Formation, Shankhu Formation, Gokarna Formation, Thimi Formation, and Kalimati clays. The Kathmandu Valley's engineering and environmental geological map (1:50,000) was prepared by the Department of Mines and Geology (Shrestha et al., 1998). It delineated different geological units such as Quaternary sediment, Plio - Pleistocene Formation, and basement rock with their engineering properties. It included all the fundamental geological and environmental data, geotechnical properties of soil having low bearing capacity, landslide, and liquefaction-prone areas, and flood hazard areas. However, this study was carried out in 1:50,000 scales which is not much applicable for local scale urban planning and land evaluation.

The present study has focused on the small area of Bhainsepati–Pharsidol, located in the Lalitpur Metropolitan City of Nepal. The objective of the present research is to prepare a detailed geological and engineering geological map of the study area in 1:25,000 scales. It has also aimed to carry out geotechnical tests of soils and sediments to evaluate the engineering properties of the materials. It is expected that the geotechnical properties of the soil will be useful for a land planner especially to evaluate the ground conditions and make a wise decision for upcoming urban planning. The geological map was prepared by using GIS, and geotechnical tests of soil were carried out in the laboratory.

The present study has revealed that the hard rocks lying in the hilly regions of the Kathmandu valley can be mapped under the rocks of both the Bhimphedi Group and the Phulchauki Group while the Quaternary valley sediments are mappable into two units as the Lukundol Formation and the Chapagaon Terrace deposits from older to younger stratigraphy respectively. Similarly, the engineering geological map has shown the engineering characteristics of soils and sediments lying at the surface and near-surface conditions of the study area. This study will be useful for land use planners while expanding the city area at and adjacent to the studied areas.

STUDY AREA

The study area is in Bhainsepati–Pharsidol, Lalitpur Metropolitan City of Nepal. The area of the smart city proposed by the government of Nepal includes 10,000 Ropani (5.08 sq. km) of land within this area. It includes the areas of Saibu in the east and north, separated by the Bagmati River in the west and Bungmati in the south extending up to the Bagmati River (Fig. 1).

METHODOLOGY

The methodology includes desk study, field studies, laboratory investigation, data analysis, and interpretation (Fig. 2). Before the field visit, available literature was reviewed thoroughly, and research gaps and main geological issues were demarcated. The main purpose of the fieldwork was to

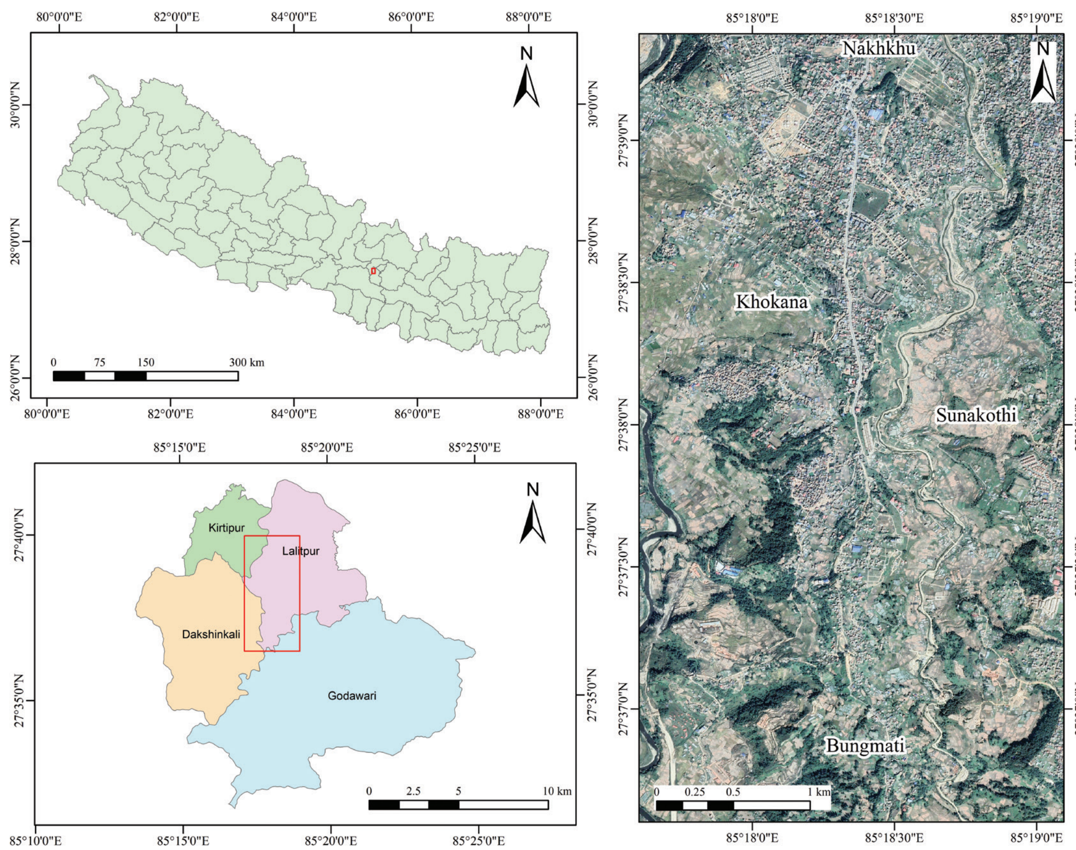

Fig. 1: Location map of the study area.

study the lithology, stratigraphy, and geological structures of the area and to prepare a geological map on a 1:25,000 scale. The field study was carried out with the help of a Brunton compass, geological hammer, measuring tape; 1:25000 scale topographic base maps, GPS, digital camera, hand lens, and 10% dilute hydrochloric acid. The first step in geological mapping was to identify the mappable lithological units in the area. For this, reconnaissance surveys were carried out across different sections within the study area. The stratigraphic classification of Stöcklin and Bhattarai (1977), Stöcklin (1980), Yoshida and Igarashi (1984), and Sah (1995) was adopted wherever possible. Major mappable lithological units were identified from the reconnaissance field survey. These surveys also provided an idea about the overall orientation of the strata, major primary sedimentary structures, and gross composition of the sediments. Reconnaissance surveys helped in developing a detailed field study plan. Sections for possible traverse routes for mapping were fixed.

A detailed field survey was carried out following the reconnaissance survey. Geological mapping included field traverse, description of the exposure, preparation of columnar section, sedimentary structures, and identification of geomorphic relation of the landforms. Lithology, sedimentary structures, and fossil contents were also shown by standard symbols.

The younger direction of the strata was identified with the help of sedimentary structures such as cross-laminations, and crossbedding. The true thickness of the strata was calculated. In some places, detailed stratigraphic columns were prepared by directly measuring the true thickness of the strata on the outcrop. The columnar sections were prepared either for each mappable unit or important lithological and tectonic boundaries (i.e. columnar sections of each geological unit based on lithological variations as well as contact relations with the underlying and overlying strata). Before starting the aerial geological mapping of the area, the strata were classified into different stratigraphic units, and the "International Stratigraphic Code" (Murphy and Salvador, 1999) was followed systematically. The strata were first classified into formations and members wherever justifiable. The Quaternary deposits were differentiated into different stratigraphic units by their texture, composition, elevation, fossils contents, and sedimentary features. After clarifying the stratigraphy of the area, geological mapping was

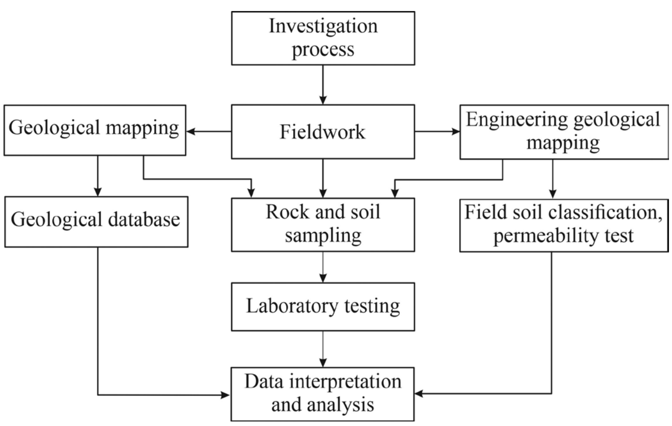

Fig. 2: Flowchart of methodology adopted in the study.

started with an attempt to extend the boundaries from the river sections side-wards. The focus was given to observing and documenting the nature of beds like sediment texture, grain size, shape, composition, and sedimentary structures. In soil-covered areas, the types of soil were identified with estimated depths along with other engineering properties. Representative samples of soils were collected from various locations for geotechnical testing in the laboratory.

The geotechnical study included an in-situ permeability test, field soil classification, and laboratory testing of soil. Altogether twelve soil samples were collected for laboratory tests (Fig. 3). Generally, soil samples were taken from 1.5 m to 2 m pits. Some soil samples were collected from the foundation of ongoing building construction. In the laboratory, particle size analysis was carried out using standard sieves. For fine-grained soils like silt and clay, hydrometer analysis was carried out. The specific gravity of soil was determined by comparing the weight with the same volume of water at 4ºC. Moisture content was determined by determining the loss of weight after heating in the oven. The moisture content was calculated as the ratio of water content to the dry soil sample. For the test, the soil samples were compacted into three layers. Generally, the soil compaction was carried out in varying moisture content i.e., 4, 8, 12, 16, and 20%. Each soil layer was compacted with 25 blows of a hammer and was compacted uniformly in each layer. The upper part of the mold was taken out. Then the soil layer above the mold was trimmed with the blade. The mold with soil sample was weighted and similarly, the compaction test was conducted for varying moisture content. The primary objective of performing a proctored test was to determine the maximum dry density (*Pd, max*) and the optimum water content (*Wopt*) at compaction effort.

The consolidation test for some undisturbed soil samples was calculated using the Casagrande logarithm of time fitting method (i.e. best-fitting). For the test, the undisturbed soil sample was prepared and placed in the consolidometer for the one-dimensional consolidation test. As it is a time-dependent process, the loading was set as per the scheduled time. The standard loading schedule consisted of a load increment ratio which was obtained by doubling the pressure on the soil to obtain values of approximately 50, 100, 200, 400, 800, and 1600 kPa. Each load increment duration was 24 hours and the change in height of the soil sample at time intervals of approximately 0.1, 0.25, 0.5, 1, 2, 4, 8, 15 and 30 min, and 1, 2, 4, 8, and 24 hours was recorded to present time deformation data which was done as per ASTM D 2435 and coefficient of consolidation and the void ratio was calculated finally.

RESULTS

The results of the studies are described in terms of geology, engineering geology, and geotechnical aspects. Descriptions of mapping with field evidence of geoengineering in different parts of the area are highlighted. Laboratory testing and their interpretation as well as kinematic analysis are elaborated in geotechnical studies.

Geology and engineering geology of the Bhainsepati-Pharsidol area

The geological map and its cross-section prepared in this study are shown in Figure 4. The geology of the study area comprises

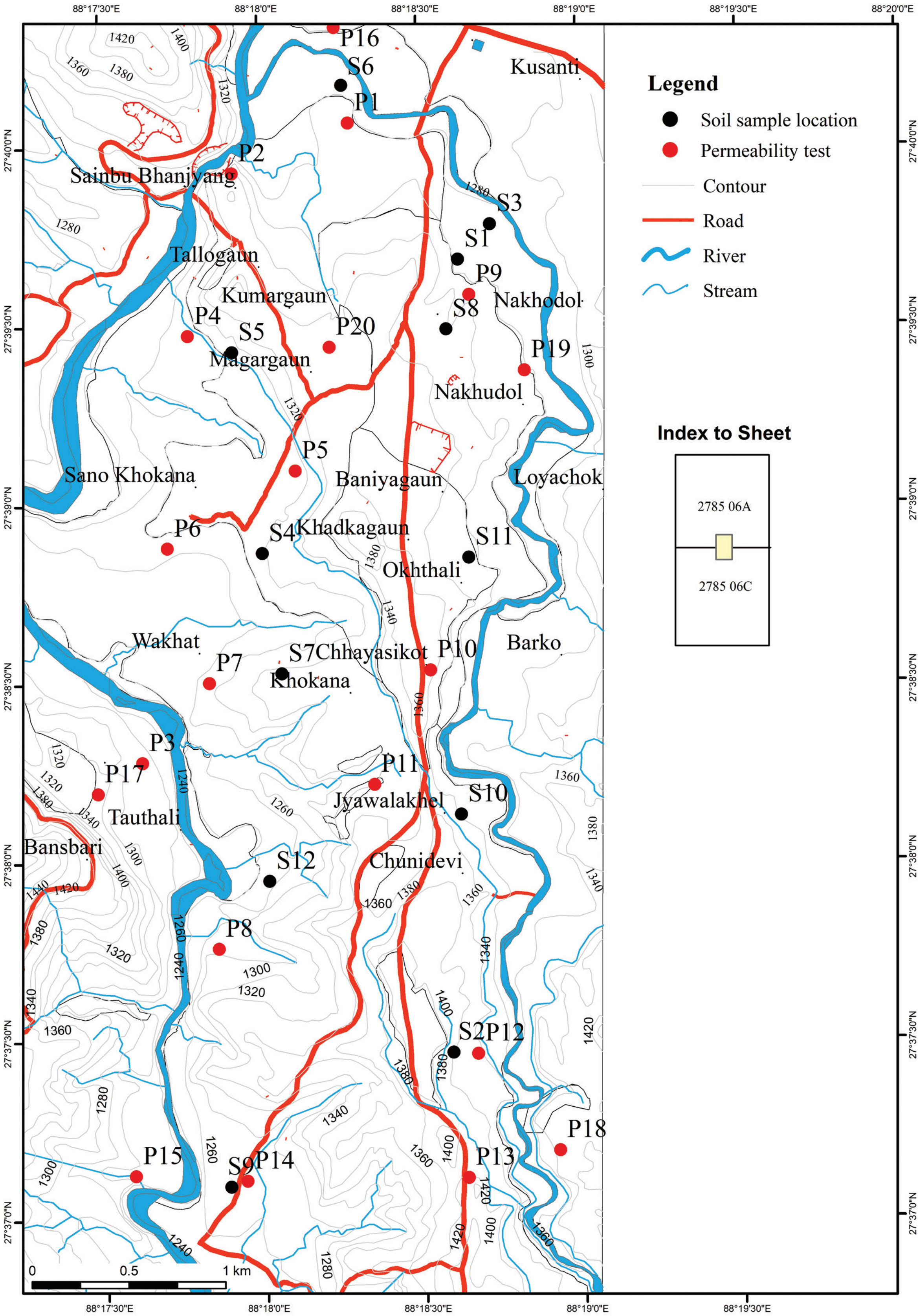

Fig. 3: A map of soil samplings and permeability test sites.

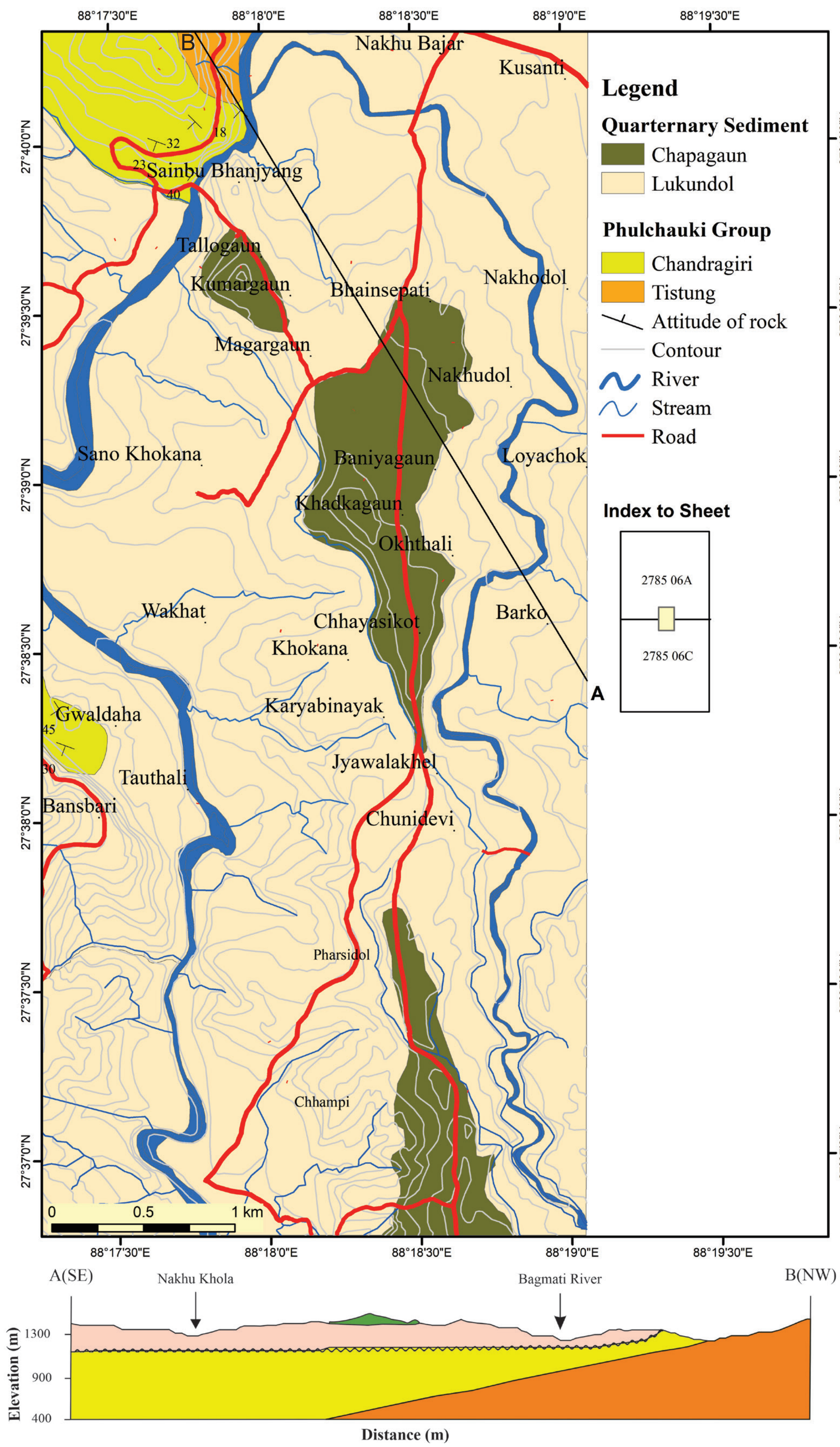

Fig. 4: Geological map of Bhainsepati-Pharsidol area and its cross-section along A–B.

the Tistung Formation and the Chandragiri Limestone of the Phulchauki Group (Stöcklin and Bhattarai, 1977) and the Lukundol Formation and the Chapagaon terrace deposits of Kathmandu Valley sediments (Yoshida and Igarashi, 1984).

Tistung Formation: It comprises slate, phyllite, and meta-sandstone in various proportions. Near Chovar the alternating beds of fine-grained meta-sandstone and thin foliations of phyllite of the Tistung Formation are exposed. Beds as well as foliations are regularly intercalated in nature (Fig. 5a). The meta-sandstone is argillaceous and dirty in nature. It consists of abundant detrital quartz, opaques, and rock fragments. Cementing materials consist of silica. Phyllite, on the other hand, is well-foliated. Sericite and chlorite are recrystallized minerals in the rock. Detrital micas are abundant. The whole succession is non-calcareous in nature.

Chandragiri Limestone: It comprises pale yellow to brown monotonous succession of limestone with partings of shale. Individual beds of the limestone vary from a few centimeters to 2 meters. Some beds are cherty in nature while others are sandy. The succession is well observed at the Jal Binayak temple in the Chovar area (Fig. 5b). Phyllite of this succession is grey, yellow, brown, and pelitic in nature. Detrital micas are abundant in phyllite. The thickness of phyllite ranges from 2 cm to 5 cm. Both the quartz and calcite veins have obliterated the beds heavily. Karst features like caverns, stalactites, stalagmites, pits, etc are distinct in several places. It is a ridge-forming unit in the area.

Lukundol Formation: The Lukundol Formation is mainly composed of coarse pebbly sand, silty sand, silt, calcareous clay, and some lignites. In the clay layer, a leaf imprint was observed at the Dhaichhap (Fig. 5c). About 10 m thick Lukundol Formation is well-exposed at the Pharsidol area in the slope cut sections (Figs. 5d, 6). The unit has cyclic deposits of clay, silt, and gravelly sand in various proportions. The upper layer comprises gravel beds. The gravel bed consists of fine-to-coarse-grained sand. Occasionally, pebbles and cobbles are also found within the sand beds.

Chapagaon terrace deposits: This unit is named as the Chapagaon terrace deposits after the Chapagaon village (Dhoundial, 1966). It comprises thick beds of pebble-cobble, sand, and mud admixtures. The gravel is derived from the host rocks of meta-sandstone, phyllite, and quartzite. Such beds are well-exposed in Bhainsepati and Champi areas (Fig. 4). A wide succession of this unit is found in the Pharsidol area (Fig. 5d).

An engineering geological map of the study area was prepared on a 1:25,000 scale showing the distribution of earth materials (Fig. 7). It shows that the study area contains mainly silty sand which covers the areas from Bhainsepati, Wakhat, Bansbari, Chunidevi, and Pharsidol. This soil was classified from field observation according to the Unified Soil Classification System (USCS) and laboratory tests. A dominant gravel layer was observed around Okhthali, Chhayasikot, and Chhunikhel areas. The size of the pebble ranges from 6 cm to 14 cm with plastic fines. The gravel layer observed in the Pharsidol area is around 4 m thick. In the area of Karyebinayak temple, the gravel layer is more than 6 m thick.

The soil that covers the areas like Kumargaun, Magargau, Sano Khokana, Barko, Nakhudol, and Sitaltar is found similar in nature. It can be classified as silty clay. This soil has more plastic and is less permeable in nature. Soil layers in these areas

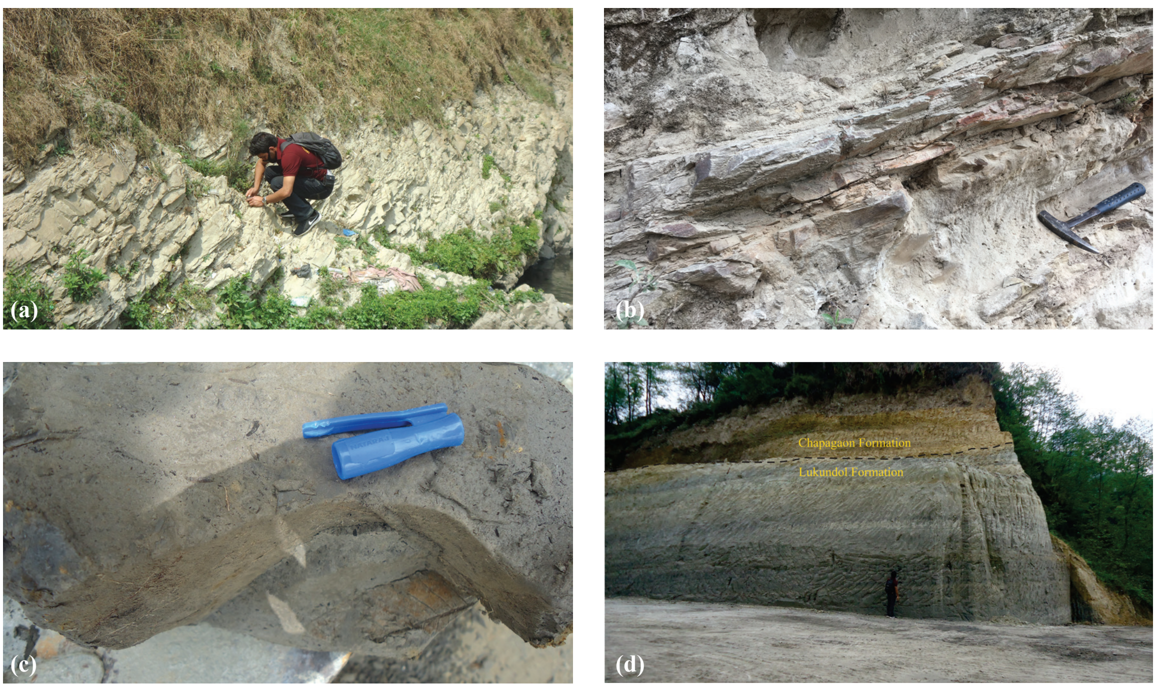

Fig. 5: (a) Outcrop of the Tistung Formation near the Chovar, (b) limestone beds of the Chandragiri Limestone with leaching surface at Chovar, (c) leaf imprints in the clay layer of the Lukundol Formation at the Dhaichhap, (d) lukundol Formation and Chapgaon Formation exposed at Pharsidol.

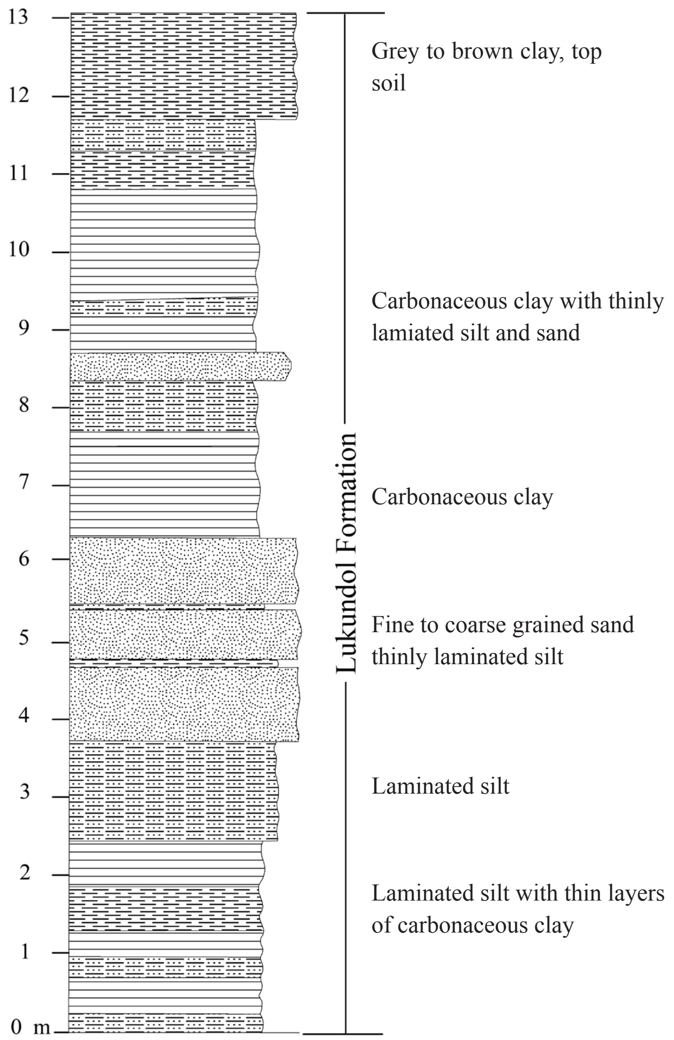

Fig. 6: Generalized columnar section of the Lukundol Formation showing the cyclic deposits of clay, silt, and sand at Pharsidol.

range from 3 m to 6 m in thickness as observed in excavated areas for foundations of buildings. Soils are very stiff in nature.

Kinematic analysis of the rock slopes was performed to assess the stability condition of the region. Possibilities of wedge failures are found in the rock slopes of the Tistung Formation (Fig. 8a,b,c) where about 44% of total joint intersections were found unstable regarding wedge failure and the unstable wedges are likely to slide towards the southwest. The rock slope at the Chandragiri Limestone was found comparatively more stable and freer from any significant instability (Fig. 8 d,e,f).

Geotechnical studies

Twelve soil samples were collected from different locations from a depth of (>1.5) m. Specific gravity, moisture content, consistency test, hydrometer test, compaction, and consolidation tests were carried out to assess the engineering properties of soil. From the particle size distribution (Table 1), it can be depicted that the soil of Bhainsepati–Pharsidol consists of clay 7–30 %, silt 57–84%, and sand ranging from 5–20%.

The liquid limit varies between 27 to 69%, the higher value observed in Sample No. S2. The plasticity index varies from 7 to 27 showing high plasticity at S2. The optimum moisture content and maximum dry density range from 11.5 to 16% and 1.3 to 1.5 g/cc respectively. The moisture content and specific gravity of the soil in the study area vary from 13 to 48% and 2.57 to 2.7 respectively (Fig. 9). From the result of field permeability of 20 different locations, the permeability value ranges from 1.38×10^{-5} to 7.28×10^{-8} (Table 2).

The consolidation test of an undisturbed soil sample from Bhainsepati (S1) and Khokana (S4) was carried out and the compressibility parameter was calculated using the Casagrande logarithm of time fitting method. The compressibility characteristics of soils are given by the coefficient of volume compressibility (mv), coefficient of compressibility (av), compression index (Cc), and swelling potential (Cs) (Table 3).

Table 1: Results of grain size analysis.

S.N.	Gravel	Sand	Silt	Clay	LL	PL	USCS	OMC (%)	MDD (g/cc)
S1	0	19.94	69.2	10.9	55	27.42	SM		
S2					69.17	41.78		13	1.32
S3	0	8.21	84.5	7.3	50.87	23.97	SP-ML	15	1.4
S4	0	5.29	83.8	10.9	61.48	51.62	ML	13	1.4
S5	0	7.41	72	20.6	38.06	30.39	ML	14	1.35
S6	0	12.74	69.1	18.2	31.85	14.63	SP-ML	12	1.29
S7	0	7.09	67.5	25.1	33.82	10.92	ML	11.5	1.3
S8	0	11.26	58.5	30.03	43.23	17.68	SP-ML		
S9	0	11.77	76.1	12.1	35.65	17.68	ML	16	1.3
S10	0	14.35	78.4	7.3	27.65	11.43	SW-ML	14	1.5
11	5.51	13.58	57.9	23	27.12	11.96	SP-ML		

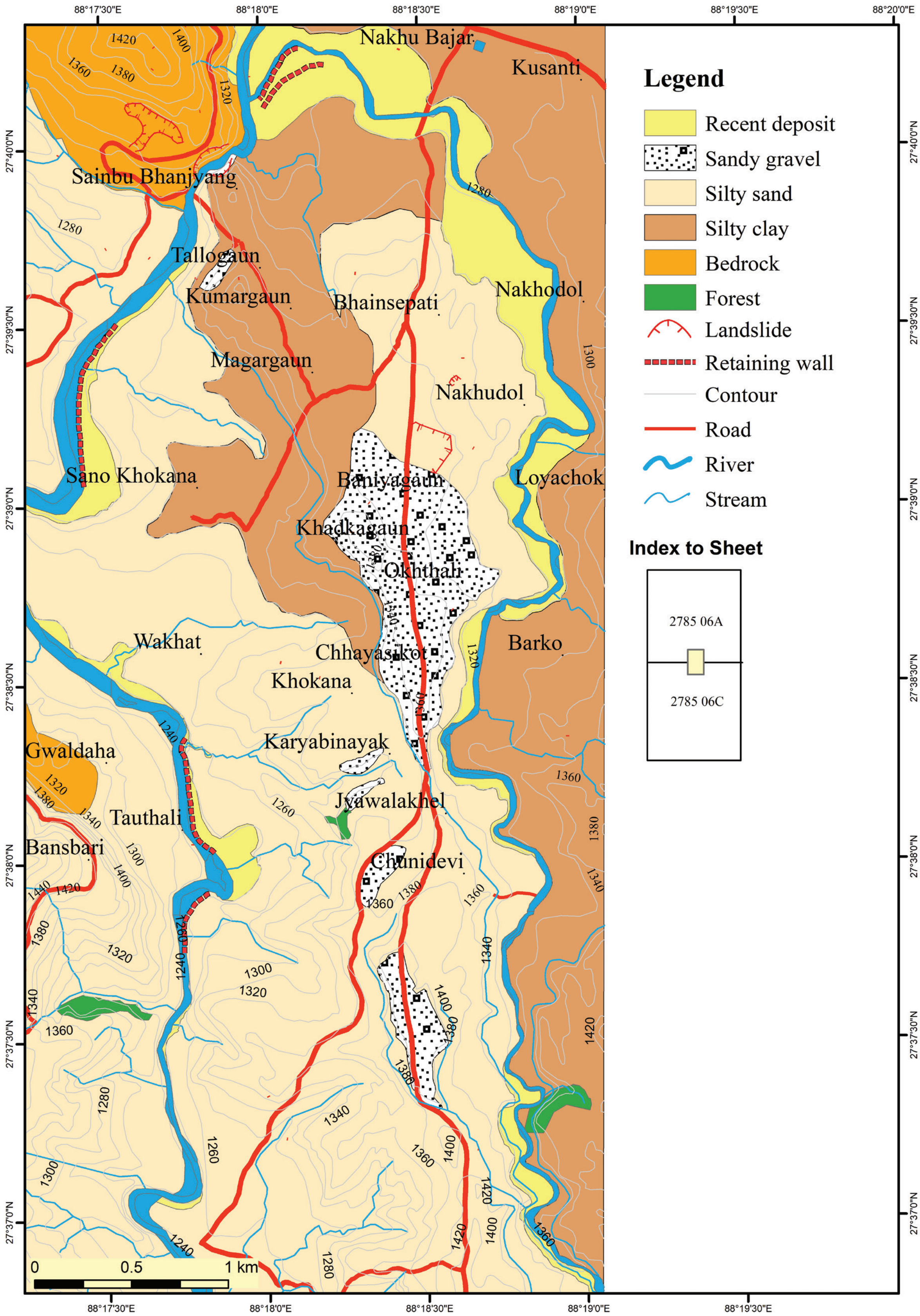

Fig. 7: Engineering geological map of the Bhainsepati–Pharsidol area.

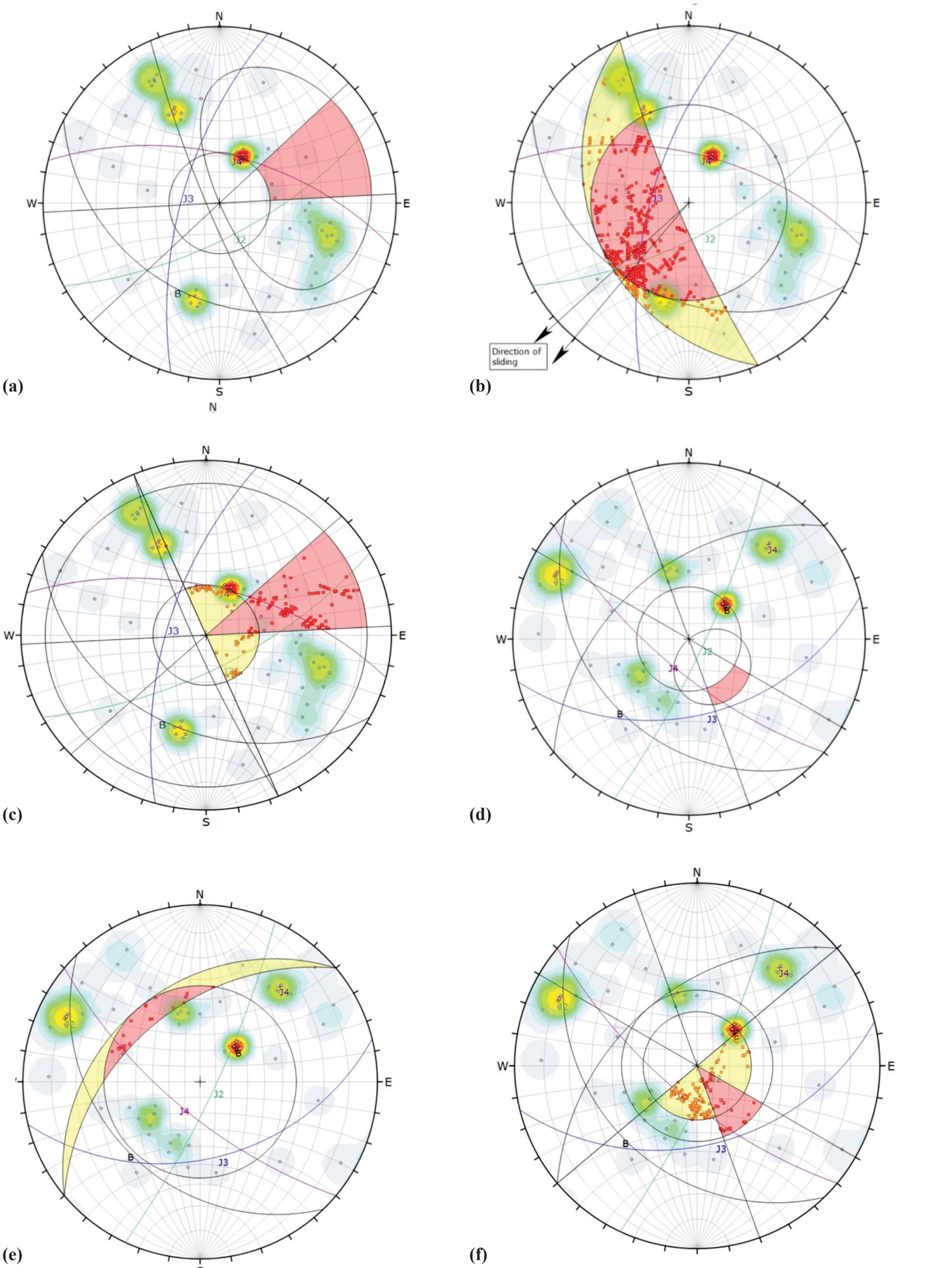

Fig. 8: Kinematic analysis of rock slope instabilities in Tistung Formation (a) planar failure, (b) wedge failure, (c) toppling failure. Rock slope instabilities in Chandragiri Limestone (d) planar failure, (e) wedge failure, (f) toppling failure.

DISCUSSIONS

Kathmandu Valley is an intermontane basin developed within the Lesser Himalayas of Nepal. The thickness of the fluvial-lacustrine sediment is more than 500 m at the central part of the basin (Kharel et al., 1998). Yoshida and Igarashi (1984) divided the basin-filled deposit into three stratigraphic groups: older-stage deposits (Lukundol Formation), middle-stage deposits (Pyangaon, Chapagaon, and Boregaon Terrace deposits), and younger-stage deposits (Gokarna, Thimi, and Patan Formations) in ascending order (Figs. 4, 10).

Lukundol Formation is found around the Nakhu Khola and Bagmati River sections and boundaries are not clear. The Lukundol Formation covers a large part of the study area and Chapagaon terrace deposits are found to be distributed along the central part of the present study. Sah (1995) divided the quaternary sediments of the Kathmandu valley into seven different units, Tarebhir Conglomerate, Lukundol Formation, Sunakothi Formation, Shankhu Formation, Gokarna Formation, Thimi Formation, and Kalimati clays in ascending order. According to him, the valley sediments of Kathmandu are of Plio-Pleistocene in age and there exists lateral facies variation within the succession. Sakai (2001) proposed a different classification scheme based on field observation and drill core study during the Paleo-Kathmandu Lake project. He classified the valley sediments into the Tarebhir Formation, Lukundol Formation, and Itaiti Formation in the southern part

Table 2: Coefficient of permeability of soils.

S.N.	Coordinates of sample locations	Permeability coefficient (k)
P1	27°39'50"N, 85°18'07"E	1.91248E-07
P2	27°39'31"N, 85°17'45"E	2.79789E-07
P3	27°39'05"N, 85°17'35"E	1.17575E-06
P4	27°38'44"N, 85°17'56"E	7.28097E-08
P5	27°38'34"N, 85°17'32"E	4.56145E-07
P6	27°38'08"N, 85°17'40" E	4.8945E-07
P7	27°37'50"N, 85°17'39"E	1.51564E-06
P8	27°36'46"N, 85°17'50"E	1.44599E-07
P9	27°36'44"N, 85°18'28"E	7.90105E-07
P10	27°37'07"N, 85°18'30"E	7.9843E-07
P11	27°37'55"N, 85°18'09"E	3.12595E-05
P12	27°38'11"N, 85°18'21"E	3.51486E-05
P13	27°39'12"N, 85°18'34"E	6.09812E-07
P14	27°36'51"N, 85°17'26"E	7.21095E-07
P15	27°36'06"N, 85°17'59"E	9.49691E-07
P16	27°39'58"N, 85°18'03"E	1.38906E-05
P17	27°38'48"N, 85°17'20"E	1.39391E-05
P18	27°36'52"N, 85°18'47"E	2.79505E-07
P19	27°38'39"N, 85°18'34"E	7.28463E-08

and the Bagmati Formation, Kalimati Formation with basal Lignite in the northern part. The distribution of geological units is well-revised in this study.

The specific gravity of soil is important to index properties, a higher value of specific gravity gives more strength for roads and foundations. The higher value of the specific gravity of the soil suggests a heavier mineral composition. The specific gravity of soil may not directly affect the engineering behavior of soil but acts as one of the suggestive tools in quickly accessing the strength and suitability of soil for engineering works. Moisture content ranges from 13% to 48%. Holtz (1969) correlated swelling potential with a common soil test. A plasticity index of more than 25 is considered a high swelling potential. The soil of Bhainsepati-Pharsidol belongs to medium swelling potential and is generally safe for the foundation.

The soil in Bungmati, Khokana, Nakhhu, and Bhainsepati is stiff, and the soil is observed to be silty clay. Permeability is low in these areas and the ranges of permeability in the overall area are 1.39 $*10^{-05}$ to 7.9 $*10^{-08}$ cm^3/s. This shows that low permeability means more clay content and vice versa. From the compaction test, it is observed that maximum dry density is 1.29 to 1.4 g/cc and optimum moisture content is 10 to 15% which shows that the soil is moderately compacted. The National Cooperative Highway Research Program (2001) developed a correlation CBR value for soils that contain 12% fines and exhibit some plasticity. From the consolidation test, the Cc of the Soil sample of Khokana and Bhainsepati was found to be 0.328 and 0.215 respectively. Coduto (1999) classified the five levels of soil compressibility based on the

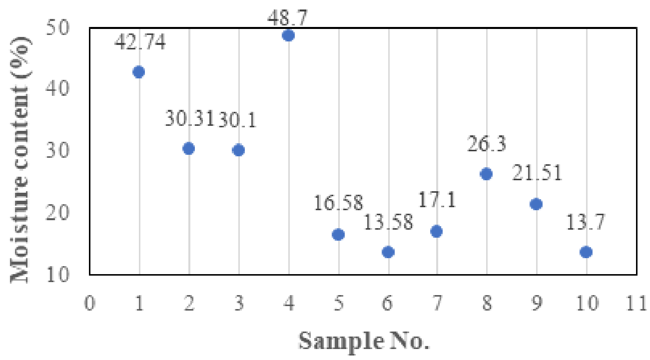

Fig. 9: Moisture content of soil samples.

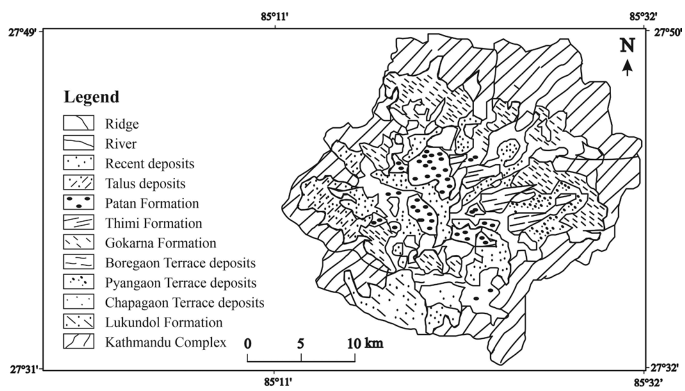

Fig. 10: Fluvio-lacustrine deposit of Kathmandu Valley (modified after Yoshida and Igarashi, 1984).

Table 3: Calculation of compressibility parameters from the consolidation test.

Location	Sample No.	Depth	Pressure (kPa)	e	C_v	a_v	m_v	C_c
			50	0.82	0.001078			
			100	0.80	0.001079			
Bhainsepati	S1	5 m	200	0.77	0.000402	0.000217	0.117183	0.215925
			400	0.73	0.000353			
			800	0.63	0.000376			
			1600	0.53	0.000309			
Khokana	S4	6 m	50	0.78	0.000500	0.00028	0.154819	0.328663
			100	0.76	0.000717			
			200	0.73	0.000494			
			400	0.69	0.000397			
			800	0.59	0.000200			
			1600	0.48	0.000243			

value of the compression index. The value of cc between 0.2–0.35 can be classified as highly compressible which is the case of the Bhainsepati and Khokana area in the present study.

CONCLUSIONS

A detailed geological map and cross-section of the Bhainsepati–Pharsidol area of Lalitpur Metropolitan City is prepared in 1:25,000 scales. The rocks and sediments found in this area can be mapped into four geological units: two units represents the hard rocks and two units for Quaternary deposits. Hard rocks are mapped under the Tistung Formation and the Chandragiri Limestone of the Phulchauki Group while the Quaternary sediments are mapped as the Lukundol Formation and the Chapagaon terrace deposits. The Tistung Formation is the succession of meta-sandstone and phyllite in various proportions while the Chandragiri Limestone is the monotonous succession of limestone, dolomite with a minor proportion of shale. The Lukundol Formation consists of pebbly sand, silty sand, silt, carbonaceous clay, and lignite deposits. Similarly, the Chapagaon terrace deposits comprise a thick bed of pebble-cobble, sand, and mud in various proportions. There is an unconformity between the Phulchauki Group and the quaternary valley deposits.

An engineering geological map was prepared in 1:25,000 scales showing the distribution of materials exposed to the surface. It shows that there is 60% silty sand, 30% silty clay, and 10% gravel-dominated succession. The area in general belongs to the moderate liquefaction hazard zone. Geotechnical properties of the soil sample show that soil is stiff, moderately plastic and moderately compacted, and has low permeability. The soil found in this area can be used as a base material for road construction since the soil has a liquid limit below 50%. The soil is found to be favorable for foundation as the PI lies below 27 i.e., has medium swelling potential. The consolidation test of the soil sample of Bhainsepati and Khokana revealed that the soil layer beneath the Chapagaon terrace deposits is highly compressible and the calcareous clay of the Lukundol Formation. The soil exists in the condition of over-consolidation (ocr.>1).

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