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Geophysical study of land subsidence: example from Pokhara basin

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ABSTRACT

Land subsidence is a serious problem in the Pokhara city and surrounding wide areas consisting of Recent debris flow deposits. Owing to their calcareous matrix the debris flow deposits are more-or-less well cemented, even though their age ranges just from 12,000 to 700 years BP. There are numerous caves and caverns in these deposits. To investigate the danger of subsidence, ground penetrating radar and electrical resistivity tomography were employed to detect and map the caves and caverns. The results are quite encouraging and the above methods are found to be quite effective in formulating the control measures to the land subsidence hazard.

INTRODUCTION

The Pokhara valley is well known for the danger of land subsidence (Fig. 1) since it is located on the Recent debris flow deposits that form the basement of the Pokhara city and wide areas surrounding it (Koirala 1998). Surveying underground conditions is the principal prerequisite for the safety and sustainability of the construction. For this purpose, geological survey including the examination of drilled cores from the construction site is commonly employed, although it is time-consuming and costly. The results are frequently not very effective due to the scanty data obtained principally from the extrapolation of spot observations to an aerial extent. Geophysical investigations, in contrast, generally provide continuous linear subsurface data and thus eliminate the danger of over-extrapolation from sparse spot data. A simultaneous geological field survey can help to make the geological concept useful for the successful interpretation of the geophysical signature.

In the present study, we utilised electrical resistivity tomography (ERT) and ground penetrating radar (GPR) at two sites in the Pokhara basin where the ground subsidence has been a grave geo-engineering problem. The present survey areas are only an example of the geophysical survey utilising the ERT and GPR coupled with geological survey. However, the results are very encouraging and demonstrate that there is an ample scope of the geophysical methods in the subsurface investigation of the Pokhara city.

METHODOLOGY

The ERT survey was carried out at an electrode spacing of 3 m (Fig. 2). Pole–dipole electrode arrangement was used for the survey. The measurement was carried out by TERRAMETER SAS300C, Manufactured by ABEM, Sweden. Details of the method are given in Pant and Reynolds (2000) and Pant (2001). In total two ERT sections were surveyed: one at Davi's Fall and the other at Mountain Museum.

The GPR survey (Fig. 3) was carried out in reflection and common mid-point (CMP) modes. The Davi's Fall site was investigated by two reflection profiles and three CMP profiles while the Mountain Museum site was investigated only by two reflection profiles. The antenna centre frequency was 50 MHz and the step size of the measurement was 0.25 m. Details of the method are given in Annan (2000). The equipment for the measurement was pulse EKKO100A, manufactured by Sensor & Software Inc., Canada.

Geological field survey was conducted in the surrounding areas of the geophysical investigation. In the two sites, deep valleys have steep cliffs on both banks and thus provide a good opportunity to study the geological sections in the area.

RESULTS AND INTERPRETATION

Geological survey was conducted on the terrace surface and in the Phusre Khola to the south and the Pardi Khola to the west of the geophysical survey sites (Figs. 4, 5). The area is composed principally of the Recent deposits of the Pokhara Formation with a thickness of 10 to 15 m. It constitutes the uppermost flat-lying gravel consisting of 10 cm to a few metres thick beds of poorly to weakly consolidated conglomerate (Fig. 6), silt, and pebbly silt (Koirala 1998). The Pokhara Formation unconformably overlies about 15 m thick late Pleistocene Ghachok Formation

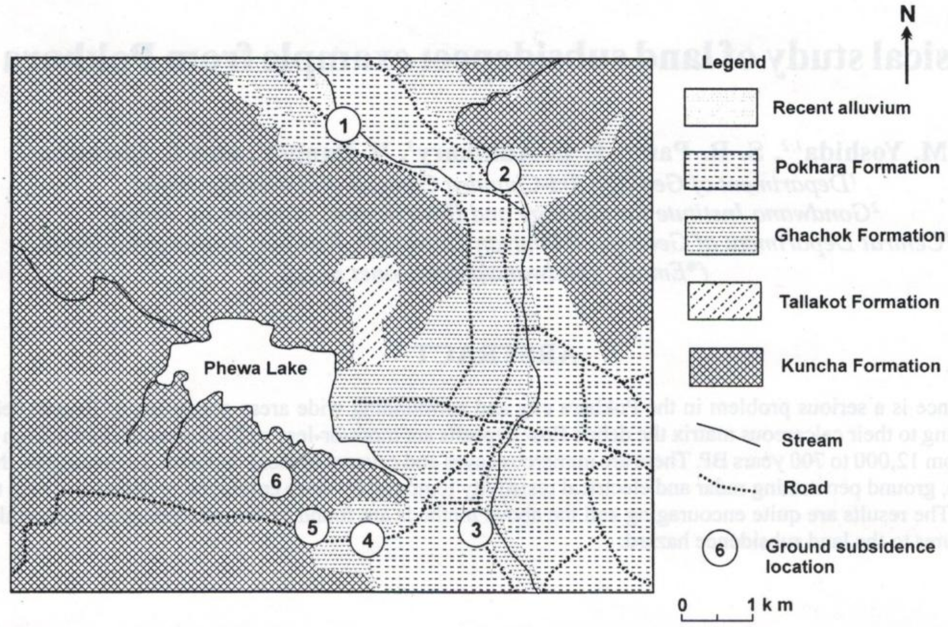

Fig. 1: Geological outline of the Pokhara city and surrounding areas (modified from Koirala 1998). Ghachok and Tallakot Formations are debris flow deposits. Locations of ground subsidence are also indicated.

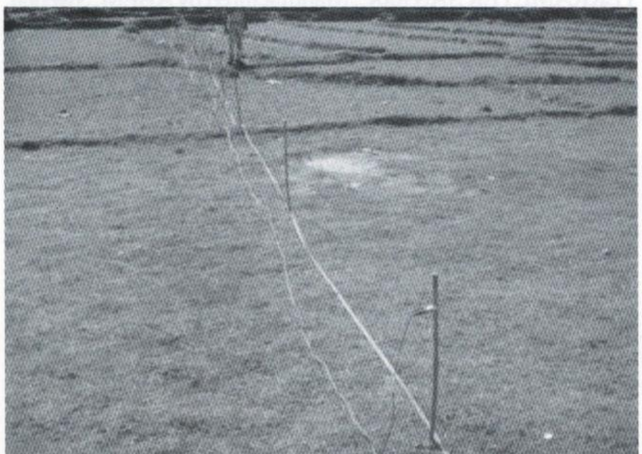

Fig. 2: ERT setting (with 3 m spacing) on Line A at Davi's Fall

Fig. 3: GPR measurement (with 25 cm spacing) on Line A at Davi's Fall site

made up of gently inclined conglomerate containing angular pebbles and cobbles (Fig. 7) intercalated with 10 cm to a few metres thick sandstone and silt layers (Koirala 1998). The Ghachok Formation rests unconformably on the phyllites of the Precambrian Lesser Himalayan metasediments occurring several meters below the riverbed.

At the geophysical investigation site, the Ghachok Formation is exposed, but it is surrounded by about 7 m high terrace of the Pokhara Formation (Fig. 1) in the neighbouring area. The ground surface at the geophysical survey site shows small undulations of less than 1.5 m in amplitude, a few metres in wavelength, and running generally in the N–S direction parallel to the Pardi Khola demarcating the western margin of the area (Fig. 4).

ERT AT DAVI'S FALL SITE

The ERT section shows a very high level of cave development between relative elevations of 84 and 94 m. It is indicated by light to dark colour shades (Fig. 8): Higher the electrical resistivity in the section higher the intensity of cave development.

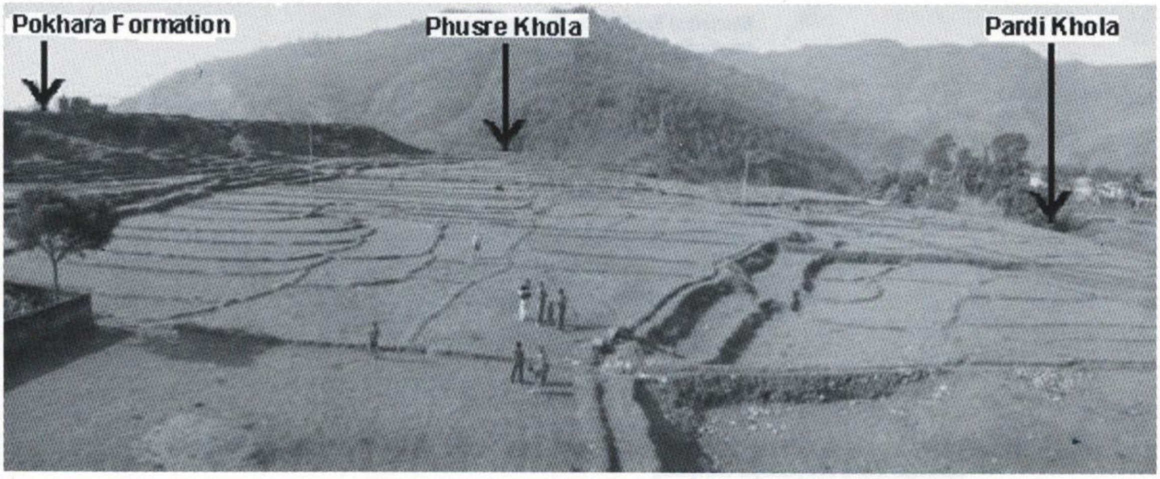

Fig. 4: The Davi's Fall site showing the Pokhara terrace (indicated as the Pokhara Formation) and the Ghachok terrace. A depression is seen to the right side of the picture.

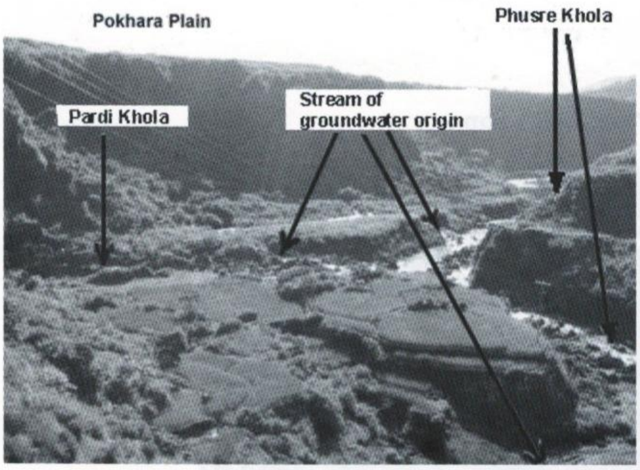

Fig. 5: The Phusre Khola, Pardi Khola, and the Pokhara terrace. The Pokhara terrace is the one shown in Fig. 4.

Fig. 6: Basal conglomerate of the Pokhara Formation exposed to the west of the survey area. The step at the left top of the picture is the reflection of the Ghachok terrace (i.e. unconformity surface).

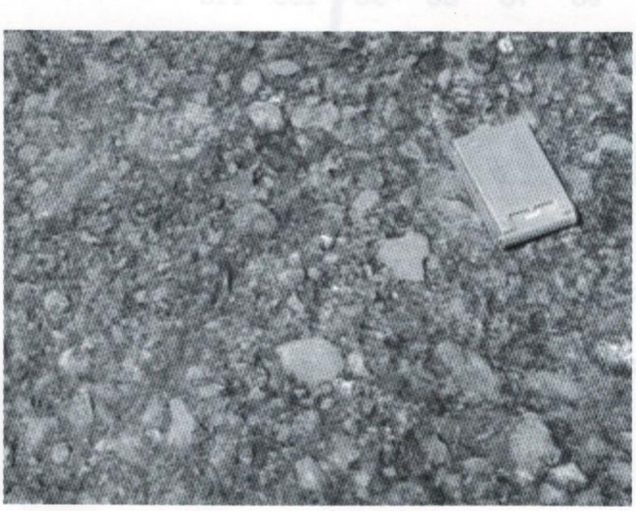

Fig. 7: Conglomerate of the Ghachok Formation

Two GPR profiles in the area indicate the presence of caves (Fig. 9). The GPR section is cluttered due to the intense development of vertical joints. The waves are scattered and diffracted from the extreme heterogeneity created by the collapse of the caves, pinnacles, and vertical joints. A high-intensity reflection between 40 and 50 m profile lengths between the time intervals of 300 to 350 ns is from the bottom of the cave. Such intense reflections are the clear indications of caves. However, the absence of such a reflection does not guarantee the absence of caves. Therefore, a comparison of ERT and GPR results is important. GPR responses largely depend on the size of the anomalous body with respect to the centre frequency used.

The results of the CMP provide only the velocity information of the top layer. There is no meaningful arrival

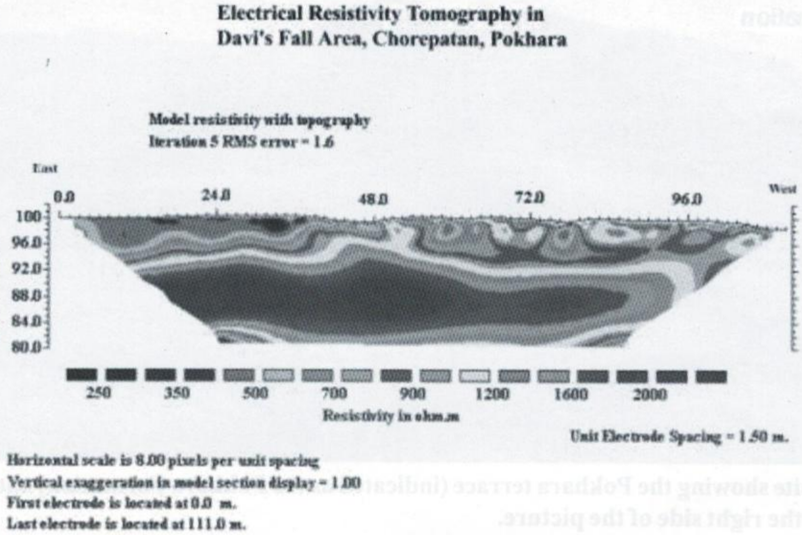

Fig. 8: ERT image of the line A (see Figs. 2 and 3) from the Davi's Fall site

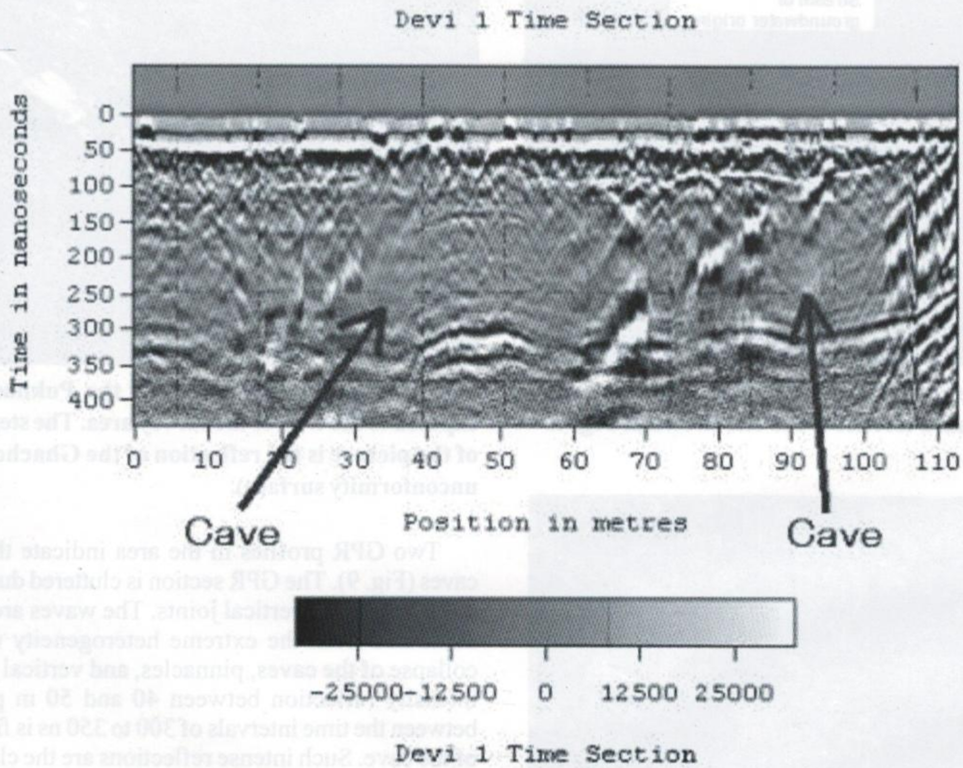

Fig. 9: GPR profile of the line A (see Figs. 2 and 3) from the Davi's Fall site

Fig. 10: View of the Mountain Museum site

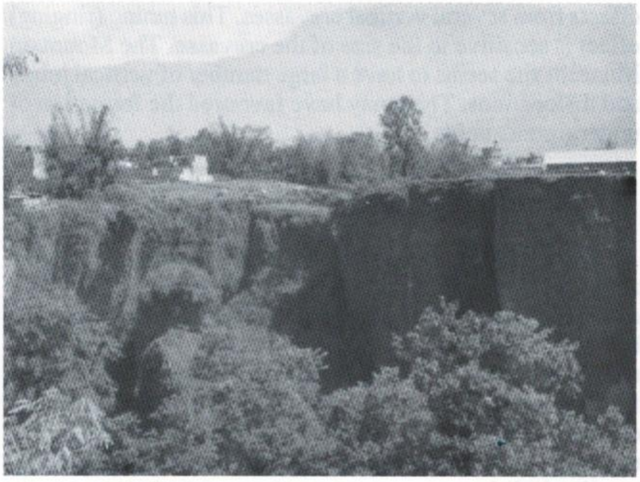

Fig. 11: Seti Khola to the NE of the survey area. The cliff is composed of the Ghachok Formation. Note well developed vertical crevasses.

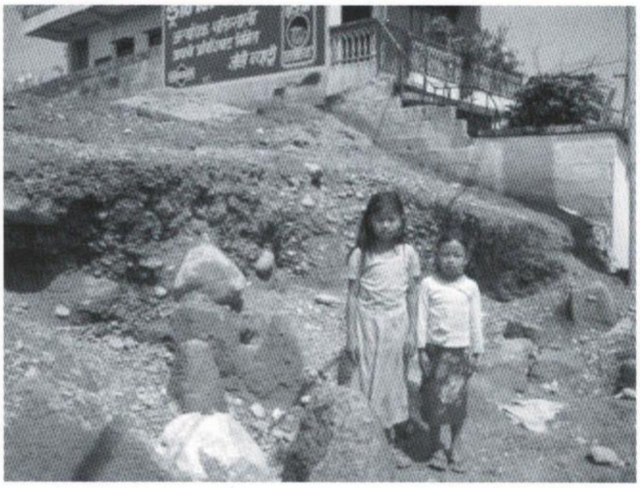

Fig. 12: Unconformity between the Ghachok (grey pinnacles below) and the Pokhara (gravel bed above) Formations observed on the roadside about 100 m north of the Mountain Museum

of signals from the deeper layers. It may be due to the scattering of the energy by the pinnacles and other lateral heterogeneities. Furthermore there are multiples due to the presence of subsurface large-scale voids in the direction of the transmitter and receiver antenna separation.

Geology and geomorphology of Mountain Museum site

The geological survey was conducted on the terrace surface and in the Seti Khola about 50 m east of the site (Figs. 10, 11). The area is composed of the uppermost flat-lying gravel bed (poorly to weakly consolidated conglomerate layer) of about 1.5 m in thickness, identified as the Pokhara Formation unconformably overlying the gently inclined conglomerate bed (with angular pebbles and cobbles intercalated with sandstone and silt layers) of about 15 m in thickness identified as the Ghachok Formation (Fig. 12). The ground surface is covered mostly by less than 1 m thick Pokhara Formation.

ERT at Mountain Museum site

The ERT is much complicated in this area. The ERT section finds one very thin but a very high electrical resistivity zone at the uppermost surface. Gravel deposits are indicated by a high electrical resistivity, and thus this layer is considered to be the Pokhara Formation. Other details are enigmatic on the ERT section in this area, possibly due to the extensive development of vertical crevasses found on the GPR image.

GPR at Mountain Museum site

The radargrams from the Mountain Museum site indicate a very strong reflection horizon whose two-way travel time is around 150 ns. This range is for a depth of about 5 m to a maximum of 7.5 m. The radargrams show zones of vertical dislocation. The radargram MM1 (Fig. 13) shows tuning

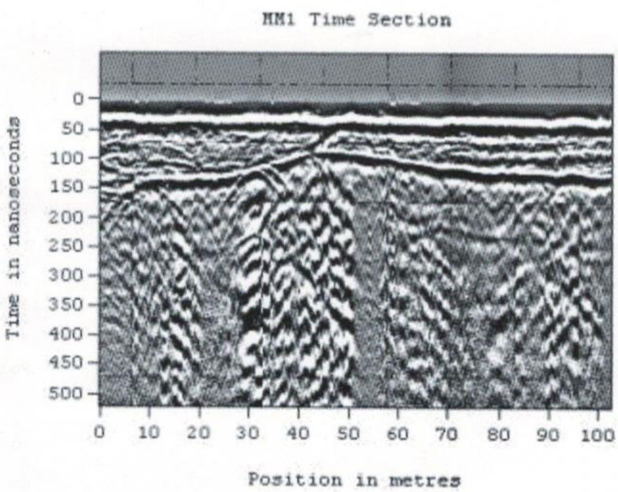

Fig. 13: GPR profile of the Line A of the Mountain Museum area. Notice on the extensive development of vertical crevasses, which is also seen on the photo view of Fig. 11.

effects from several vertical crevasses. This tuning (ringing) effect is sensitive to the size of the crevasse. The Mountain Museum site seems to have a large number of vertical joints and dislocations. They may have favoured the formation of underground voids.

CONCLUSIONS

The GPR survey has given very good results, especially at the Mountain Museum site. On the other hand, the ERT data need careful interpretation. For future studies it would be better to test the sites by both methods. Furthermore for the GPR it would be better to use two antenna centre frequencies to detect the voids. Even a small void can be detected applying this technique. An accurate topographic map and levelling are very important to reliably interpret the geophysical data.

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