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Hydrogeological study along Marsyangdi River terraces: A case study in Lamjung, Tanahun and Gorkha districts

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ABSTRACT

Groundwater, one of the major natural resources of Nepal, is widely used in supplying domestic water and irrigation across the nation. Hand pumps and tube wells are used in the Terai area for the groundwater while in hilly and mountain regions, springs serve as the primary groundwater sources. However, there has been limited studies and investigations related to groundwater in hilly areas, making it difficult for study of groundwater potential and occurrence. In this study, the hydrogeological study has been carried out in the terraces formed by the Marsyangdi River for investigating the groundwater potential of the particular area. The study uses the geophysical survey data of vertical electrical sounding (VES) and associated electrical resistivity tomography (ERT) and drilling data from deep tube-wells established within the study area.

The study reveals that the study area possesses noteworthy groundwater potentials in the Harrabot and Garambesi of Lamjung, Kalimati and Khaharephant of Tanahun and Ranitar and Chyanglitar of Gorkha Districts respectively. The discharge rates of these seven tube wells ranges from 3.33 to 13.8 lps showing low to high groundwater potential in these areas. The lithology extracted from the drilling samples predominantly reveals clay, silty clay with gravel cuttings and sand materials with fractured rocks which are considered to be suitable zone for aquifers formation. The major sources of groundwater recharge in these areas could be rainfall infiltration and Marsyangdi river flow. This study shows that these deep tube-wells can be a good groundwater sources for domestic and irrigation purposes and those insights gained from this research will be useful in further groundwater exploration efforts in different areas of the hilly regions comprising of similar geology, spring distribution and geomorphology..

Keywords: Groundwater, Marsyangdi terrace, geophysical survey, deep tube well

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INTRODUCTION

Nepal, despite being the one of the richest country in terms of water resource availability, water is not easily accessible and equal for all population of the country. Groundwater resources in inter-mountain basins and Terai regions of the country have been relatively well explored and utilized; however, groundwater resources in the hills and mountain regions are yet to be investigated and assessed in detail. Groundwater resources in the middle hills of Nepal perform a major role in supplying domestic and irrigation water and in regulating river flows. However, there has been little systematic study of groundwater within the region, making it difficult to access and utilize properly. Limited research from river flows and water chemistry indicates a significant role for groundwater storage in the Himalayan foothills within fractured basement aquifers (Jenkins et al., 1995; Anderman et al., 2012). However, groundwater resources remains poorly characterized in terms of both the hydrogeological setting and water usage.

The Middle Hills and mountain regions are believed to have a lower groundwater potential than the main groundwater basins present in the Terai and the mid-hill valleys, such as Kathmandu and the Dang, where groundwater is used extensively for agriculture, industry and water supply. Groundwater resources are more limited due to the presence of low permeability crystalline basement and steep slopes which helps to increase run-off and reduce the potential for groundwater recharge. However groundwater in the slopes of the middle hills is likely to occur in the areas where the weathered bedrock zone and fractures zones in the underlying basement aquifers. Fluvial sand and gravel aquifers deposited within both the active and former river floodplains are also likely to store significant groundwater resources.

Groundwater is available in almost many parts of the country but the amount and the depth in which it is available vary drastically from place to place. It depends on lithological composition such as sediments like sands, gravels form good reservoir or aquifer but layers containing of finer grains of sediments like silts, clay do not form good reservoir. Such layers contain higher porosity but lack of permeability. Similarly, there is less chance for groundwater to be trapped in the hard-compact rock terrain, but good chance exists in fractured, jointed rocks. Based on the preliminary hydrogeological studies (Grimmelmann, 1984), unfractured high-grade metasediments of Midland Group and crystalline rocks of higher Himalaya are considered to constitute poor aquifer quality formations. Unconsolidated loose sediments of Terai and inner Terai, karstified and fractured carbonate rocks of midland and Tethys group has developed good potential source for groundwater. Limestone and quartzites of Tethys Group are considered to have developed some good aquifers (Shrestha et al., 2018).

Occurrence and movement of groundwater in the Terai area have been well investigated but the exploration of groundwater in hilly regions is a challenging task because of its rough topography and geological settings. Nowadays, geophysical exploration methods (VES, ERT) surveys become quite popular for groundwater exploration over the last few years.

Marsyangdi, one of the tributary of the Narayani River system which ultimately confluence with the Ganges River is an important river in Nepal. This river starts from Manang and flows in Lamjung, Gorkha and Tanahu districts before its confluence with Trishuli River in Mugling. Marsyangdi River formed large terraces in these districts where the settlements are mostly spread. The study area is Harrabot, Garambesi of Lamjung, Kalimati and Khaharephant of Tanahu and Ranitar and two DTWs at Chyanglitar of Gorkha District all lying on the terraces formed by Marsyangdi River. Geophysical method (ERT and VES) was used for groundwater exploration on these areas. Based on geophysical interpretation, deep tubewells were constructed at Kalimati, Khaharephant, Ranitar and two DTWs at Chyanglitar area and investigation deep tubewells were constructed at Harrabot and Garambesi Area of Lamjung. The lithological data were compared with geophysical interpretation to verify the reliability of geophysical survey and found coherent. After tubewell construction, pumping test has been completed. The discharge, static water level and dynamic water levels were observed in which transmissivity and hydraulic conductivity were also calculated from the datas of pumping test. The observed discharge at Harrabot, Kalimati, Garambesi, Ranitar, Khaharephant and two DTWs at Chyangli area are 5 l/s, 8 l/s, 4 l/s, 3.33 l/s, 13.8 l/s and 7.7 l/s, 6.7 l/s respectively with 18 m, 34.17 m, 10.1 m, 1.81 m, 0.6 m and 12.3 m, 42.46 m drawdown respectively. The ground water extracted in these areas are being used for irrigation and domestic water purposes.

This study will apply hydro-geophysical and hydrogeological methods to determine the groundwater potential of the area of Marsyangdi Terraces and evaluate the aquifer characteristics of the groundwater aquifer. This will help in accessing the suitability of the study area for the establishment of water scheme which will not only serve the people of the area but if successful same methodology can replicate in other parts of the country having similar kind of terrain.

Location and accessibility

Administratively, the study area lies in three districts namely Lamjung, Gorkha and Tanahun of Gandaki Province covering Ward No. 8 of Rainas Municipality of Lamjung, 7 of Palungtar Municipality of Gorkha, and 10 of Bhanu Municipality of Tanahun districts (Fig. 1). Harrabot, Kalimati, Garambesi, Ranitar and Khaharephant area are easily accessed by road connection via. Dumre-Besisahar-Chame Road whereas Chyanglitar lies about 4.5 km north from Nayapul at the Prithvi Highway. Marsyangdi River is the main drainage and groundwater recharge source of these areas. The elevation of these study areas ranges from 370 to 590 m above sea level.

Geology and hydrogeology

Geologically, the study area falls under Ranimatta Formation which can be correlated to the Kuncha Formation and Fagfog Quartzite of the Lesser Himalaya, center Nepal and is mainly dominant by monotonous succession of green-grey, dark grey, and bluish grey phyllite, phyllitic metasandstone, gritty phyllite, and quartzite (Fig. 2). The Marsyangdi River near Chyangli is influenced by local faults. South east directional flow of the

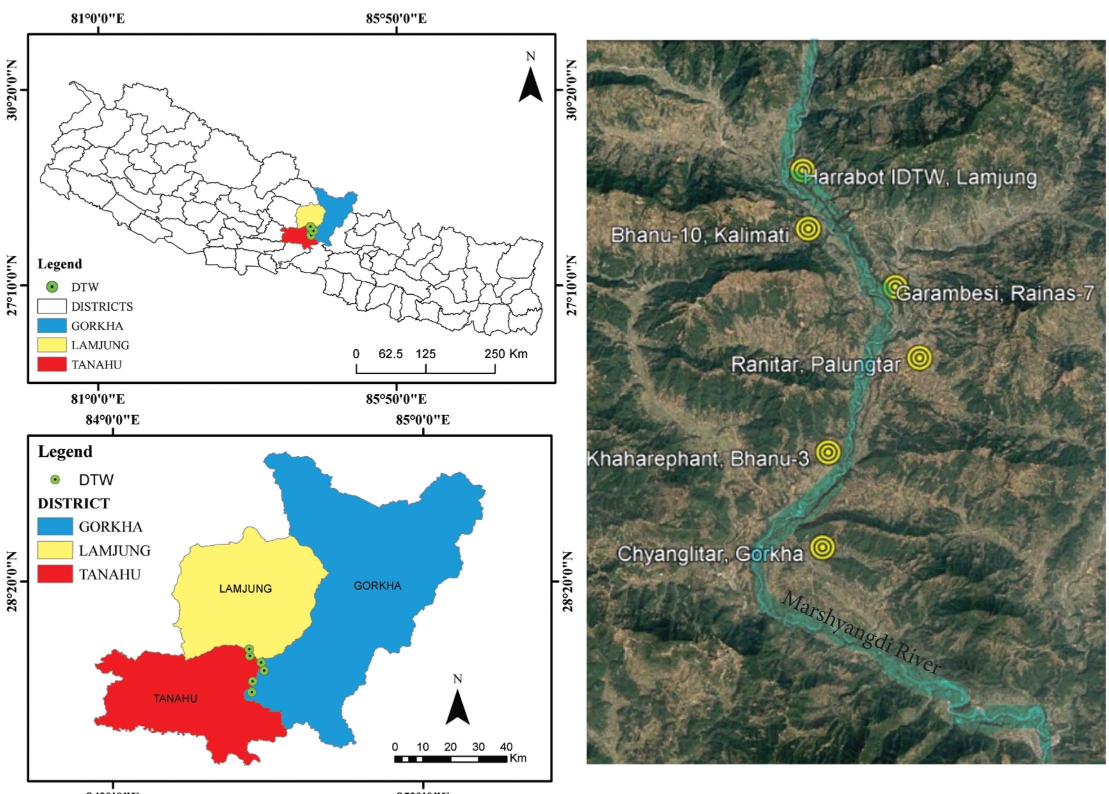

Fig. 1: Location map of the study area.

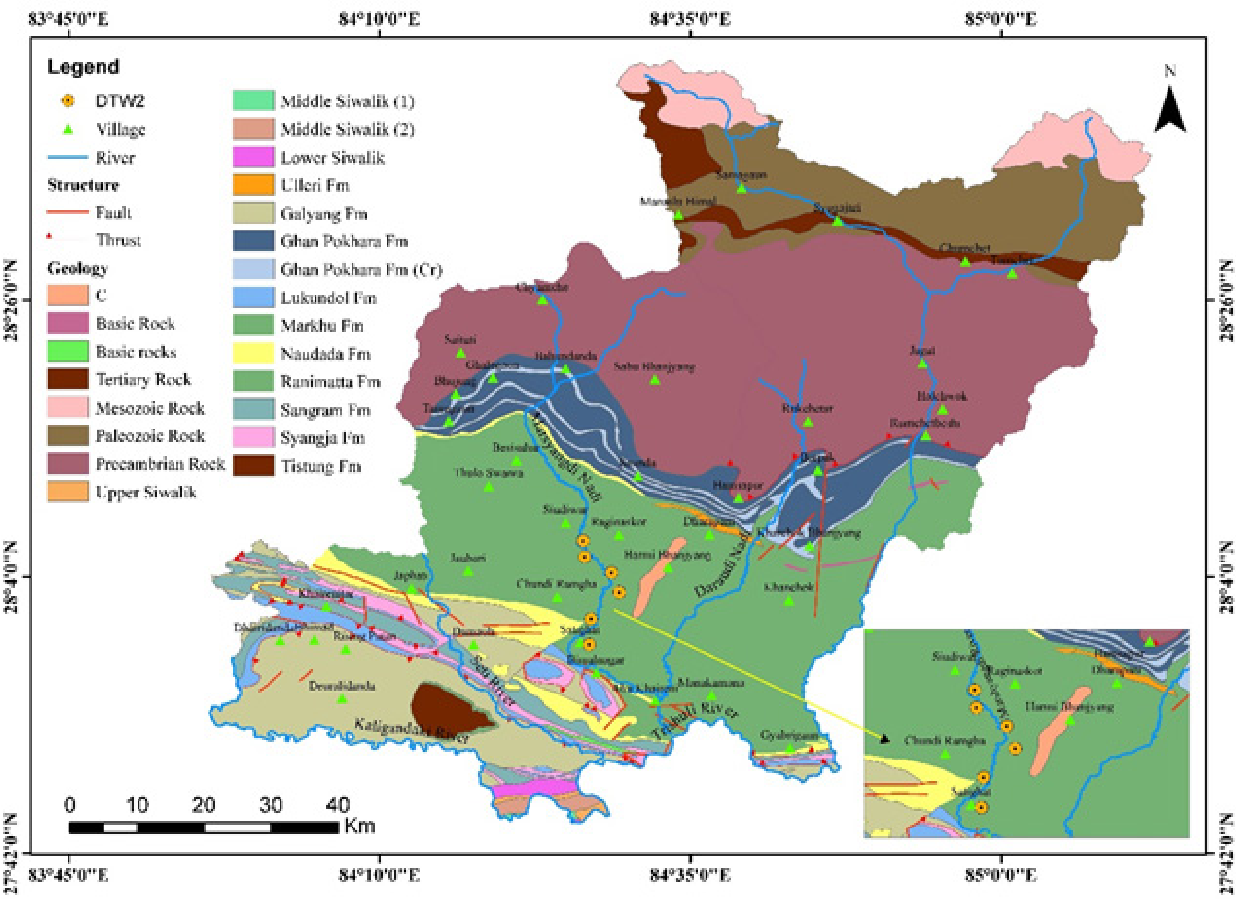

Fig. 2: Geological map of the study area (modified after DMG, 2020).

Marsyangdi River takes straight to south and the eastward due to couple of local faults which are nearly perpendicular and meets around Dumre Bazar.

The major rivers flowing through the study area is Marshyangdi River. Many seasonal streams like: Baguwa Khola, Paudi Khola, Dharapani Khola, Telkati Khola, Chiti Khola, Sawdi Khola etc. drains the study area and are the tributaries of the Marshyangdi River. The Marshyangdi River meets the Trishuli River at Muglimg which later mixes with Kali Gandaki and Budi Gandaki River and becomes Narayani River, one of the biggest rivers of Nepal.

Groundwater resources in the middle hills have not been systematically investigated and very few estimates of the groundwater resource exist. However, investigations by Kansakar (2002) suggest the annual groundwater recharge in Nepal's mid-hills is 1,723 million cubic metres and Andermann et al. (2012) conclude that the groundwater storage within the fractured basement aquifers of the Middle Hills significantly influences river discharge. Groundwater discharge occurs in the form of springs and seepages and plays a critical role in the lives of the people in the hills. In some mountain areas it is the only source of water for drinking and irrigation. Springs also helps to maintain base flow in rivers, and sustain aquatic ecosystems.

GEO-PHYSICAL METHODS FOR GROUNDWATER EXPLORATION

Electrical resistivity tomogram (ERT)

ERT was used in the Kalimati, Khaharephant and Ranitar Areas for groundwater exploration purposes. The method of survey in the present study is two-dimensional electrical resistivity tomography (2D ERT). The 2D ERT survey is useful in locating the area with higher probability for groundwater along the profile line for the depth of more than 150 m. the filed data are filtered, processed and treated with RES2DINV software.

Principally, the electrical resistivity tomogram worked on the basis of physical properties of electrolyte solutions, compactness, hardness and grain size of rocks. Electrical resistivity tomography survey is usually conducted following the various arrangements of four electrodes, two current (C1 and C2) and two potentials (P1, P2) depending upon the specific purpose. There are many electrode arrangements, which can be used in the 2D ERT field survey. The Wenner and Schlumberger are used as configuration method for better vertical as well as lateral resolution.

Vertical electrical resistivity (VES)

VES method was used for groundwater exploration in Chyangli area. The electrical properties of rocks in the upper part of the earth's crust are dependent upon the lithology, porosity, and the degree of pore space saturation and the salinity of the pore water. Saturated rocks have lower resistivity than unsaturated and dry rocks. The higher the porosity of the saturated rock, or the higher the salinity of the saturating fluids, the lower the resistivity. The presence of clays and conductive minerals also reduces the resistivity of the rock. The resistivity of earth materials can be studied by measuring the electrical potential distribution produced at the earth's surface by an electric current that is passed through the earth.

The resistance R of a certain material is directly proportional to its length L and cross-sectional area A, expressed as (Eq. 1).

$$R = Rs * L/A \text{ (Ohm)} \quad (1)$$

Where, Rs is known as the specific resistivity, characteristic of the material and independent of its shape or size with Ohm's Law (Eq. 2).

$$R = dV/I \text{ (Ohm)} \quad (2)$$

Where, dV is the potential difference across the resistor and I is the electric current through the resistor. The specific resistivity may be determined by Equation 3.

$$Rs = (A/L) * (dV/I) \text{ (Ohm m)} \quad (3)$$

When carrying out a resistivity sounding, current is led into the ground by means of two electrodes. With two other electrodes, situated near the centre of the array, the potential field generated by the current is measured (Fig. 3). From the observations of the current strength and the potential difference, and taking into account the electrode separations, the ground resistivity can be determined. During a resistivity sounding, the separation between the electrodes is step-wise increased (in what is known as a Schlumberger Array), thus causing the flow of current to penetrate greater depths. When plotting the observed resistivity values against depth on double logarithmic paper, a resistivity graph is formed, which depicts the variation of resistivity with depth. This graph can be interpreted with the aid of a computer, and the actual resistivity layering of the subsoil is obtained. The depths and resistivity values provide the hydrogeologist with information on the geological layering and thus the occurrence of groundwater.

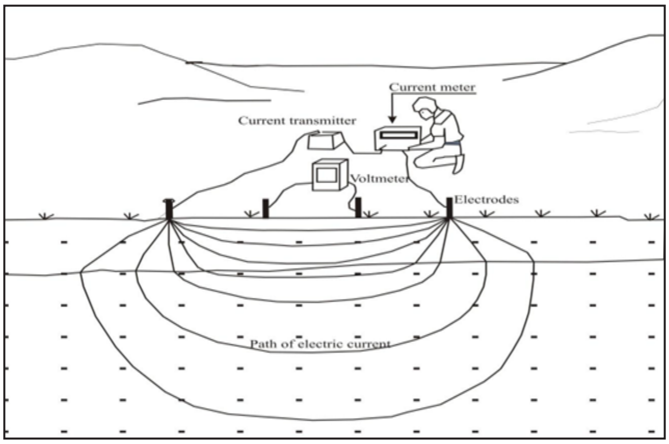

Fig. 3: Principles of resistivity measurements (Robinson and Coruth, 1988).

FIELDWORK ASSESSMENT

3 numbers of VES line were surveyed in Chyangli area to cover the study area. Survey points were so selected that they form a regular grid and maximum subsurface information could be obtained (Fig. 4). The electrode spacing was so maintained that it could give information of lithological layers up to a depth of about 150 m (Table 1).

Two profile lines of 400 m was used in both Kalimati and Khaharephant area of Tanahun District for groundwater potential exploration (Figs. 5, 6). The depth of the investigation depends upon the length of the profile and spacing between electrodes. To collect the information from depth below 100 m and deeper, a full length of profile 400 m was used. Two numbers of ERT line were surveyed in 5 m minimum electrode spacing with total length of 800 m (400 m each) (Table 2, 3).

Fig. 4: VES points and DTW at Chyangli, Gorkha District.

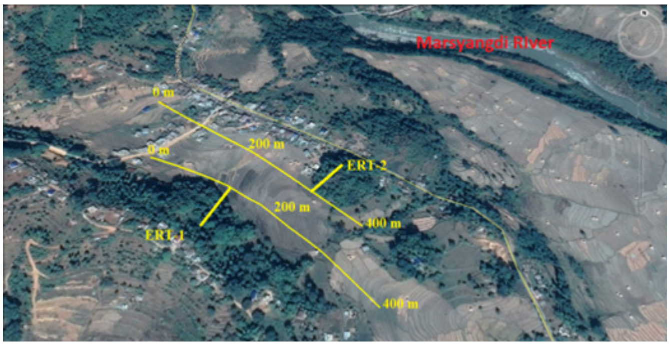

Fig. 5: Orientation of cable layout of ERT profile at Kalimati, Tanahun District.

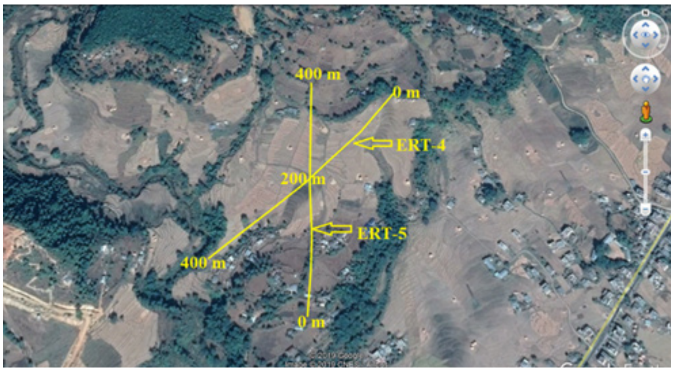

Fig. 6: Orientation of cable layout of ERT profile at Khaharephant, Tanahun.

Table 1: Details of VES survey location at Chyangli, Gorkha.

VES Number	Location	Northing	Easting	Total length of AB/2 (m)
VES 1	Aane Barala, Palungtar Municipality-7	27.96506	84.44266	440
VES 2	Bodgaon, Palungtar Municipality-7	27.95875	84.44682	440
VES 3	Palungtar Municipality-7	27.95315	84.43159	400

Three profile lines of 990 m was used in Ranitar area of Gorkha District for groundwater potential exploration (Fig. 7). To collect the information from depth below 150 m and deeper, a full length of profile 990 m was used. Three numbers of ERT lines were surveyed in 10 m minimum electrode spacing with total length of 2970 m (990 m each) (Table 4).

Interpretation of Field Data

Interpretation of VES data

Field electrical sounding data are in the form of apparent resistivity for each current electrode separations, which consists the information about the depth to and details of hydrogeological section in the survey area. This information is obtained by decoding these field data using various interpretation techniques. Inverse Slope method and Curve Matching method were used in the field to obtain quick first-hand information. Detail interpretations were analyzed later in the office using computer software. An iteration software (IPIWIN2) is used to iterate curves of VES. The first step in using IP Win is data input, the second step is data error correction, the next step is adding data point, and the last step is cross section creation. The smooth curves taken through the set of data points were interpreted quantitatively by the method of partial curve matching (Figs. 8, 9, 10).

Discussion of VES result

The electrical sounding survey revealed a multi-layer earth in the project area. Local geology and resistivity value observed by survey was base for interpretation. The layers consist of topsoil with silt, sand, gravel, fractured rock, fresh rock at different depths. The Chyanglitar area can be categorized in two hydrogeological conditions; lower terrace and upper terrace. The loose sediments deposited by the Marsyangdi River forms lower terrace. It is composed of inter layering of silt, sand and gravel layers followed by bed rock. Sand and gravel layers of lower terraces are good aquifers for groundwater. The bedrock is expected to encounter at depth greater than 100 bgl. The upper terrace comprised of residual and colluvium deposits at top, coarse material at up to 25 m from bgl and followed by bed rock. The expected bed rocks are green-gray, dark gray and bluish gray phyllite, phyllitic metasandstone, gritty phyllite, and quartzite of the Seti Formation which can be correlated with Kuncha Formation of central Nepal Lesser Himalaya.

Interpretation of ERT data

Resistivity tomogram and lithological interpretation of ERT-1 (Kalimati)

This profile runs on the right bank of the Marsyangdi River on the agricultural terraces on alluvial deposit with profile starting from upstream direction and ending at the downstream direction. The total length of the profile is 395 m and the representative electrical resistivity tomogram is presented in Figure 11.

Table 2: Details of 2D-ERT survey location at Kalimati, Tanahun.

Location	Profile No.	Length (m)	Start		End	
			Northing	*Easting*	*Northing*	*Easting*
Kalimati, Bhanu-10	ERT-1	395	28°5’ 38.12”N	84°26’26.78”E	28°5’31.24”N	84°26’40.27”E
	ERT-2	395	28°5’ 42.15”N	84°26’25.16”E	28°5’35.48”N	84°26’38.63”E

Table 3: Details of 2D-ERT survey location at Khaharephant, Tanahun.

Location	Profile No.	Length (m)	Start		End	
			Northing	*Easting*	*Northing*	*Easting*
Khaharephant, Bhanu-3	ERT-4	395	28°0’18.60”N	84°26’45.92”E	28°0’9.34”N	84°26’35.08”E
	ERT-5	395	28°0’7.17”N	84°26’40.80”E	28°0’19.42”N	84°26’40.93”E

Table 4: Details of 2D-ERT survey location at Ranitar, Gorkha.

Location	Profile No.	Length (m)	Start		End	
			Latitude	Longitude	Latitude	Longitude
Ranitar, Palungtar-5	ERT-1	990	253361	3105515	253453	3104517
	ERT-2	990	253748	3105105	252898	3104982
	ERT-3	990	253695	3105190	253728	3104238

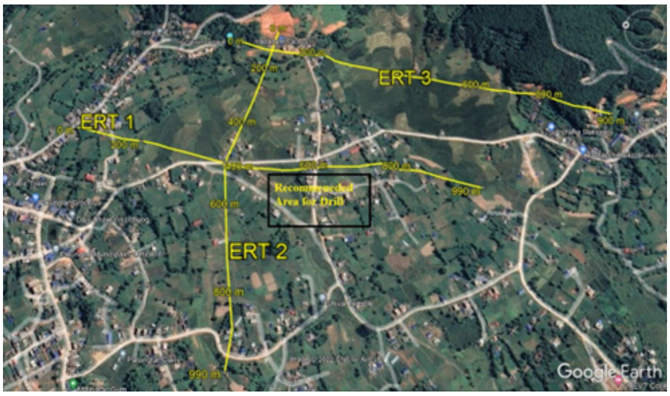

Fig. 7: Orientation of cable layout of ERT profile at Ranitar, Gorkha.

The lithological section can be interpreted as multi layered model. Top layer represents dry soil with clay and silty clay with thickness of 5–10 m from start to end of the profile line.

Second layer represents the silty sand with the clay layer which is present from Chainage 110–240 m at the depth of 4–10 m. The same layer is also present from Chainage 270 m to end of the profile line at the depth of 10 m. Saturated medium to coarse sand is present from Chainage 70 m to 120 m at the depth of 10–20 m.

Saturated sand and gravel is present from Chainage 130 m to 240 m. The same layer is also present at the depth of 17–20 m from Chainage 275 to 320 m. Silty sand with clay is present from the Chainage 200 m to 270 m at the depth of 25–30 m.

VES Field curve and interpretation result

Layer No.	VES -1			
	Resistivity [Ohm-m]	Formation thickness (m)	Depth (m, bgl)	Expected lithology
1	197	1.2	1.2	Topsoil
2	87.3	4.12	5.32	Silt, fine sand
3	41.5	18.4	29.7	Silt
4	93.7	26.1	49.8	Silt, fine sand
5	23	46.1	95.9	Fractured/ crushed zone
6	733	-	-	Fresh rock

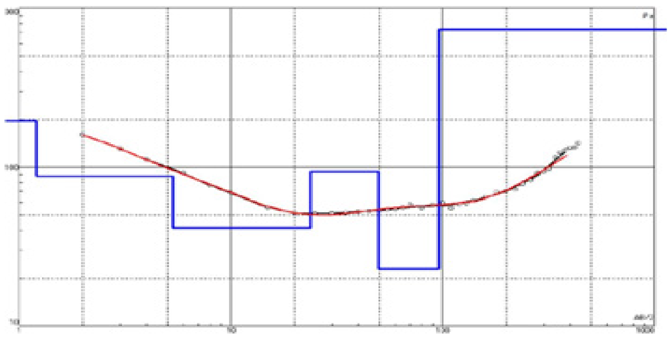

Fig. 8: Interpretation of VES 1 at Aane Barala, Palungtar Municipality-7, Gorkha.

Layer No.	VES -2			
	Resistivity [Ohm-m]	Formation thickness (m)	Depth (m, bgl)	Expected lithology
1	480	1.72	1.72	Topsoil
2	216	3.37	5.1	Course sand, gravel
3	81.5	19.6	24.7	Silt, fine sand
4	45.3	134.3	159	Fractured/ weathered bedrock
5	532			Fresh Rock

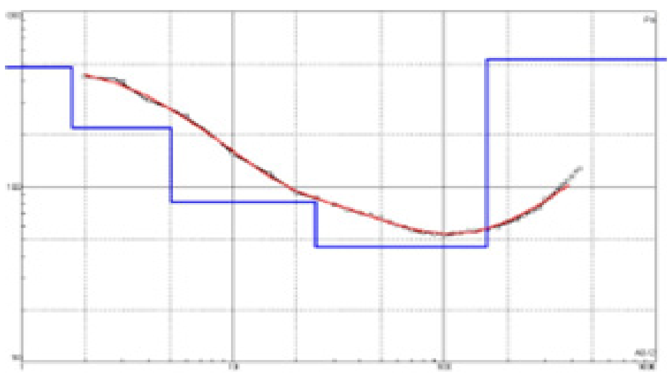

Fig. 9: Interpretation of VES 2 at Bodgoan, Palungtar Municipality-7, Gorkha.

Layer No.	VES -3			
	Resistivity [Ohm-m]	Formation thickness (m)	Depth (m, bgl)	Expected lithology
1	228.2	1.40	1.40	Topsoil
2	136	31.55	32.95	Fine sand
3	353.7	17.46	50.41	Coarse sand, gravel
4	64.78	61.42	111.8	Silt, fine sand
5	1301			Fresh rock

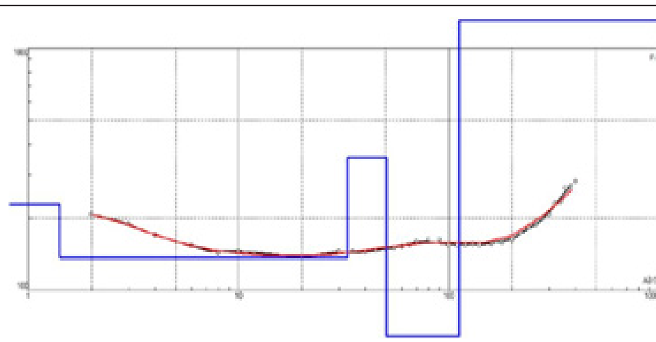

Fig. 10: Interpretation of VES 3 at Palungtar Municipality-7, Gorkha.

Resistivity Tomogram and Lithological Interpretation of ERT-2 (Kalimati)

This profile runs on the right bank of the Marsyangdi River on the agricultural terraces on alluvial deposit with profile starting from upstream direction and ending at the downstream direction. The total length of the profile is 395 m and the representative electrical resistivity tomogram is presented in Figure 12.

The lithological section can be interpreted as multi layered model. Top layer represents dry soil with clay and silty clay from Chainage 190 m to end of the profile line. Saturated fine sand is present from the Chainage 90 m to 165 m with thickness 7 m (Chainage 140 m) to 28 m (Chainage 105 m). Second layer represents the saturated medium to coarse sand which is present from Chainage 170–210 m at the depth of 5–8 m. Silty sand with clay layer is present from Chainage 40 m to 70 m at the depth of 7 m with thickness 9 m. The same layer is also present from Chainage 200 m to 260m at the depth of 12 m with the thickness of 10 m and from Chainage 300 m to 360 m at the depth of 9–11 m. Saturated sand and gravel is present from start of the profile to Chainage 160 m and again from Chainage 210 m to the end of the profile. Based on the ERT-1 and ERT-2, water table is found to be at 5–8 m depth around the survey area. Saturated sand and gravel layer is found from 20 to 25 m depth at the proposed drill location.

Resistivity tomogram and lithological interpretation of ERT-4 (Khaharephant)

This profile runs on the right bank of the Marsyangdi River on the agricultural terraces on alluvial deposit with profile starting from upstream direction and ending at the downstream direction. The total length of the profile is 395 m and the representative electrical resistivity tomogram is presented in Figure 13.

The lithological section can be interpreted as multi layered model. Top layer represents dry soil with clay and silty clay from Chainage 190 m to end of the profile line. Saturated fine sand is present from the Chainage 90 m to 165 m with thickness 7 m (Chainage 140 m) to 28 m (Chainage 105 m). Second layer represents the saturated medium to coarse sand which is present from Chainage 170–210 m at the depth of 5–8 m. Silty sand with clay layer is present from Chainage 40 m to 70 m at the depth of 7 m with thickness 9 m. The same layer is also present from Chainage 200 m to 260 m at the depth of 12 m with the thickness of 10m and from Chainage 300 m to 360 m at the depth of 9–11 m. Saturated sand and gravel is present from start of the profile to Chainage 160 m and again from Chainage 210 m to the end of the profile.

Resistivity tomogram and lithological interpretation of ERT-5 (Khaharephant)

This profile runs on the right bank of the Marsyangdi River on the agricultural terraces on alluvial deposit with profile starting from downslope direction and ending at the upslope direction. The total length of the profile is 395 m and the representative electrical resistivity tomogram is presented in Figure 14.

The lithological section can be interpreted as multi layered model. Top layer with low resistivity values represents clay and silty clay layer and silty clay layer from starting to end of the profile line. The thickness of the layer is 11 m (at Chainage

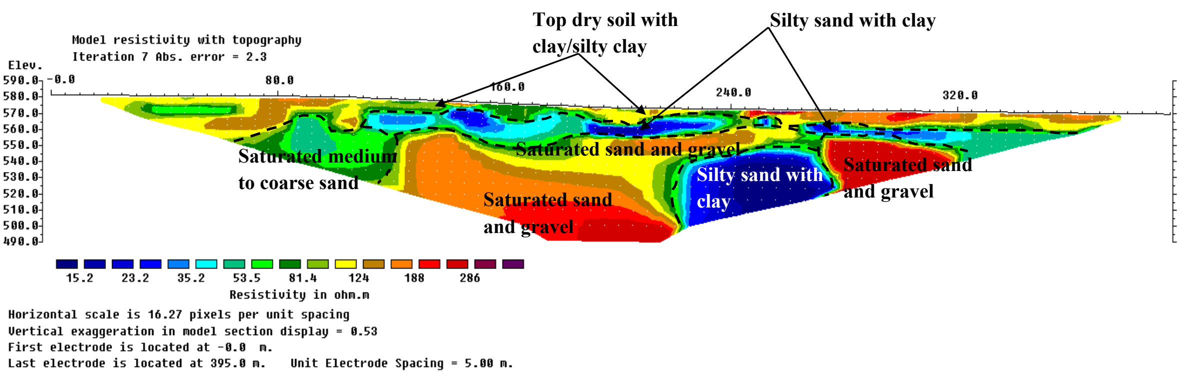

Fig. 11: Interprepative resistivity Tomogram of ERT-1, Bhanu Municipality-10, Kalimati, Tanahun.

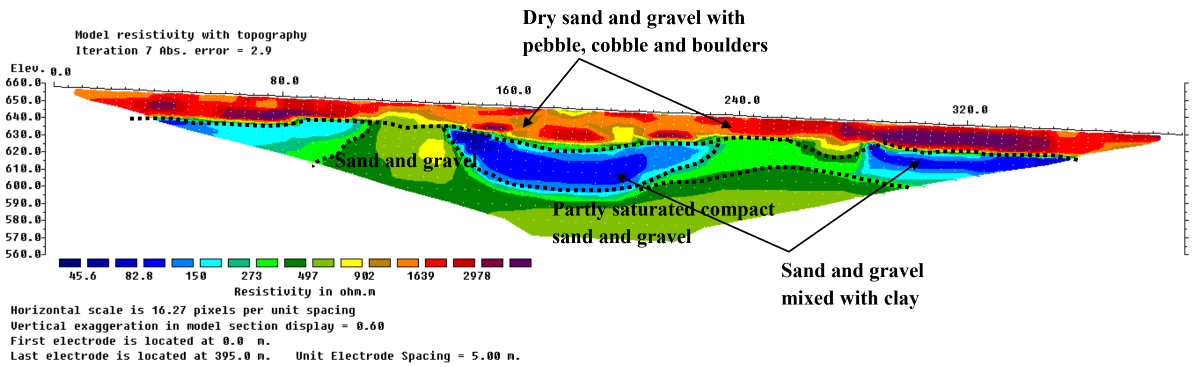

Fig. 12: Interprepative resistivity Tomogram of ERT-2, Bhanu Municipality-10, Kalimati, Tanahun.

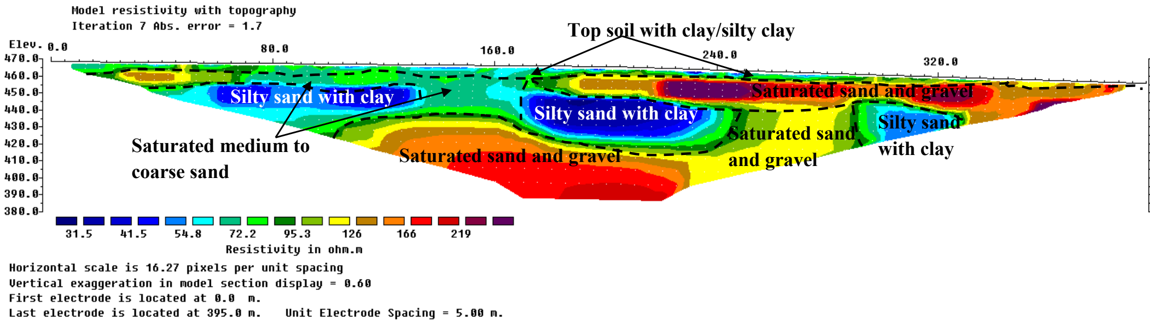

Fig. 13: Interprepative resistivity Tomogram of ERT-4, Bhanu Municipality-3, Gauriphant, Tanahun.

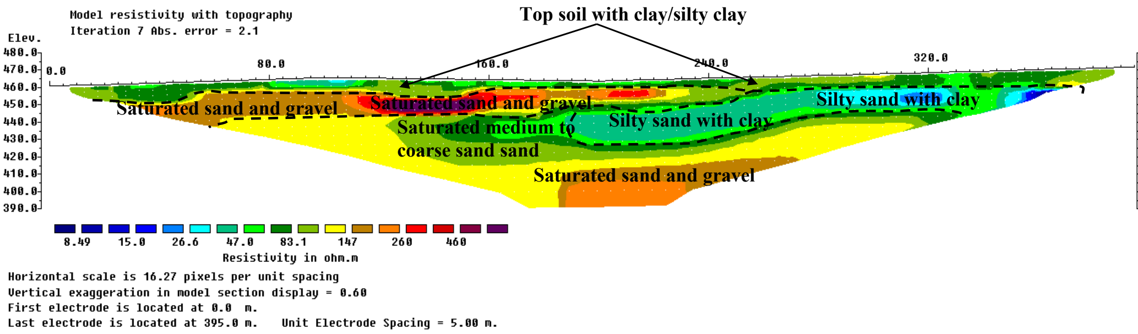

Fig. 14: Interprepative resistivity Tomogram of ERT-5, Bhanu Municipality-3, Khaharephant, Tanahun.

40 m), 4 m (at Chainage 200 m) and 10 m (at Chainage 340 m). Second layer with thickness 10-15 m represents silty sand with clay layer. Saturated medium to coarse sand is indicated from Chainage 130 m to 190 m at the depth of 14–21 m. High resistivity values on the third layer from starting of the profile to the end of the investigation depth indicates saturated sand and gravel layer. Based upon ERT 4 and 5, water table is found at 8 to 10 m depth around the survey area. Top soil with clay/ silty clay is found up to 5–8 m depth. Saturated sand and gravel is found up to 20 m depth. 20 m thick silty sand with clay layer is found on third layer. From 30 to 40 m depth saturated sand and gravel is found and extend towards the greater depth.

Resistivity tomogram and lithological interpretation of ERT-1 (Ranitar, Palungtar, Gorkha)

This profile is laid on Palungtar area with starting of the profile from North and ending of the profile towards South direction. The minimum spacing between the electrodes is 10 m. The total length of the profile is 990 m and the representative electrical resistivity tomogram is presented in Figure 15.

Top layer with resistivity value 56.5 Ωm–157 Ωm indicates dry compact soil from start to Chainage 180 m of the profile. The thickness of the layer is 14 m at Chainage 50 m and 12.5 m at Chainage 150 m of the profile. Resistivity value from 28 Ωm–80 Ωm indicates top dry soil with silt and clay/ cultivated soil from Chainage 180 m to end of the profile. The thickness of the layer is 14.5 m at Chainage 190 m, 7.2 m at Chainage 330 m, 13.5 m at Chainage 500 m, 5.2 m at Chainage 630 m, 14.5 m at Chainage 810 m and 8 m at Chainage 950 m of the profile.

Second layer with resistivity value of 29 Ωm–80 Ωm indicates presence of top dry soil with silt and clay/ cultivated soil from start to Chainage 180 m of the profile. The thickness of the layer is 6 m at Chainage 90 m and 5 m at Chainage 150 m of the profile. The resistivity value ranging 56 Ωm-112 Ωm indicates the presence of saturated silt, sand and gravel from 180 m to end of the profile. The thickness of this layer is 25.5 m at Chainage 300 m, 18.5 m at Chainage 450 m, 29.5 m at Chainage 630 m, 15.5 m at Chainage 800 m and 23.5 m at Chainage 930 m.

Third layer with resistivity ranging from 29 Ωm–57 Ωm indicates presence of clay mix with sand and gravel from the Chainage 200 m–530 m, 570 m–640 m, 690 m–750 m and 820 m–900 m of the profile. The thickness of this layer is 44 m at Chainage 300 m, 47 m at Chainage 410 m, 52 m at Chainage 510 m, 56 m at Chainage 610 m, 36 m at Chainage 720 m and 29 m at Chainage 850 m.

Fourth layer with resistivity value above 157 Ωm indicates presence of highly compacted sediment/ gravel with medium to large boulders from Chainage 60 m to 600 m of the profile. This layer can be observed at the depth of 16 m at Chainage 640 m, 79 m at Chainage 290 m and 103 m at Chainage 510 m of the profile. Resistivity value from 112 Ωm–157 Ωm indicates saturated sand and gravel from Chainage 460 m to 810 m of the profile. This layer can be observed at the depth of 85 m at Chainage 650 m and 56 m at Chainage 790 m.

Resistivity tomogram and lithological interpretation of ERT-2 (Ranitar, Palungtar, Gorkha)

This profile runs on Palungtar area with starting of the profile from North and ending of the profile towards South direction. The minimum spacing between the electrodes is 10 m. The total length of the profile is 990 m and the representative electrical resistivity tomogram is presented in Figure 16.

Top layer with resistivity value 150 Ωm–1500 Ωm indicates dry compact soil from start to Chainage 230 m of the profile. The thickness of the layer is 23 m at Chainage 40 m, 30 m at Chainage 130 m and 11.5 m at Chainage 200 m of the profile. Resistivity value from 10 Ωm–70 Ωm indicates presence of top dry soil with silt and clay/ cultivated soil from 190 m to 540 m of the profile. The thickness of the layer is 16.5 m at Chainage 230 m, 11.5 m at Chainage 320 m, 22 m at Chainage 480 m and 24.8 m at Chainage 520 m of the profile. The resistivity value ranging 60 Ωm–300 Ωm indicates presence of dry soil from Chainage 530 m–670 m and 750 m to end of profile. The thickness of the profile is 20 m at Chainage 550 m, 16.5 m at Chainage 640 m, 21.7 m at Chainage 800 m and 10 m at Chainage 960 m of profile.

Second layer with resistivity value of 150 Ωm–1500 Ωm indicates presence of highly compacted sediment/ gavel with medium to large boulders from Chainage 40 m to 270 m of the profile. This layer can be observed at the depth of 26 m at Chainage 100 m, 21 m at Chainage 160 m and 11 m at Chainage 260 m. The resistivity value between 60 Ωm–1400 Ωm indicates presence of saturated silt, sand and gravel from Chainage 280 m–730 m of profile. The thickness of this layer is 36 m at Chainage 320 m, 16 m at Chainage 480 m, 30 m at Chainage 660 m, 36 m at Chainage 400 m and 26 m at Chainage 500 m. The resistivity value between 60 Ωm - 300 Ωm indicates the presence of saturated sand and gravel that extends from Chainage 710 m to 850 m of the profile. This layer can be observed at the depth of 23 m at Chainage 720 m, 20 m at Chainage 800 m and 15 m at Chainage 830 m of profile.

Third layer with resistivity ranging from 10 Ωm–70 Ωm indicates presence of clay mixed with sand and gravel from the Chainage 270 m to 710 m. The thickness of this layer is 13 m at Chainage 320 m, 33 m at Chainage 400 m, 56 m at Chainage 480 m, 53 m at Chainage 550 m and 36 m at Chainage 640 m.

Fourth layer with resistivity value ranging from 50 Ωm–70 Ωm indicates presence of saturated sand and gravel from the Chainage 270 m to 710 m. The thickness of this layer is 16.5

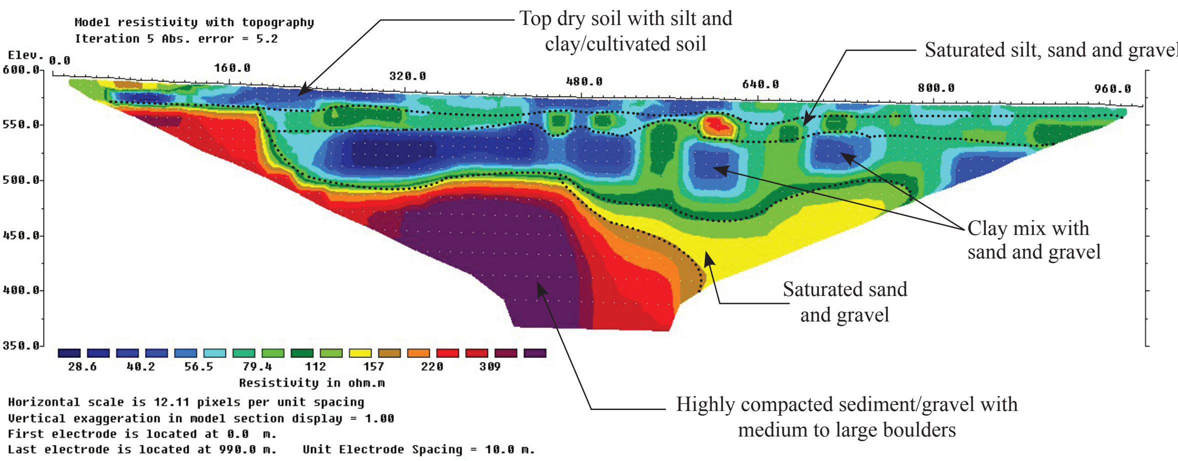

Fig. 15: Interprepative resistivity Tomogram of ERT-1, Ranitar, Palungtar Municipality, Gorkha.

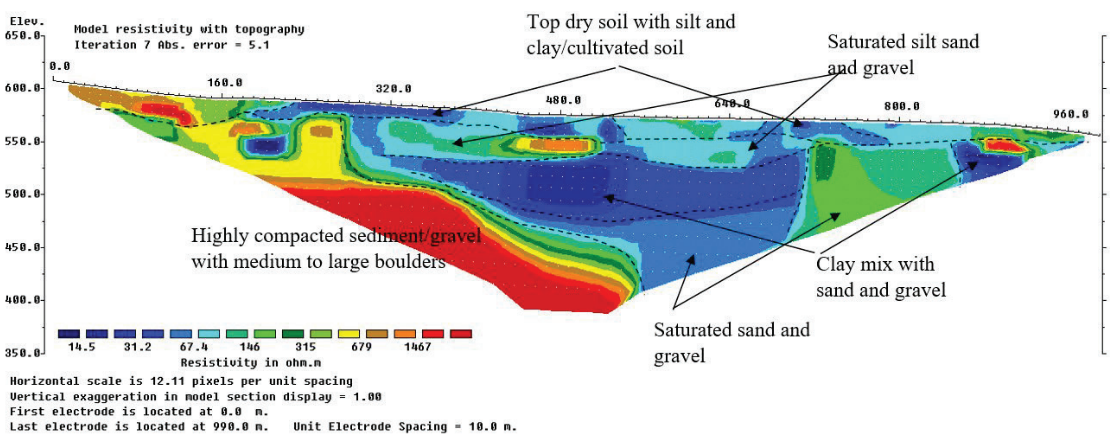

Fig. 16:Interprepative resistivity Tomogram of ERT-2, Ranitar, Palungtar Municipality, Gorkha.

m at Chainage 320 m, 90 m at Chainage 400 m and 76 m at Chainage 480 m. This layer can be observed at the depth of 160 m at Chainage 560 m, 133 m at Chainage 640 m and 144 m at Chainage 600 m.

The last layer with resistivity value ranging from 600 Ωm–1500 Ωm indicates presence of highly compacted sediment/ gravel with medium to large boulders from Chainage 270 m to 550 m. This layer can be observed at the depth of 76 m at Chainage 320 m, 90 m at Chainage 400 m, 110 m at Chainage 480 m and 130 m at Chainage 540 m.

Resistivity tomogram and lithological interpretation of ERT-3 (Ranitar, Palungtar, Gorkha)

This profile runs on Palungtar area with starting of the profile from North and ending of the profile towards South direction. The minimum spacing between the electrodes is 10 m. The total length of the profile is 990 m and the representative electrical resistivity tomogram is presented in Figure 17.

Top layer with resistivity value 200 Ωm–1150 Ωm indicates dry compact soil from start to Chainage 160 m of the profile. The thickness of the layer is 22.5 m at Chainage 50 m, 45 m at Chainage 100 m and 50 m at Chainage 120 m of the profile. Resistivity value from 60 Ωm–100 Ωm indicates presence of saturated silt and gravel from 160 m to 190 m of the profile. The thickness of the layer is 37.5 m at Chainage 180 m of the profile. The resistivity value ranging from 20 Ωm–60 Ωm indicates presence of top dry soil with silt and clay/ cultivated soil from Chainage 190 m–690 m of profile. The thickness of the profile is 12 m at Chainage 260 m, 17.5 m at Chainage 320 m, 18 m at Chainage 480 m and 16 m at Chainage 640 m of profile. Resistivity value ranging from 200 Ωm–1100 Ωm indicates the presence of dry compact soil from Chainage 680 m to end of the profile. The thickness of this layer is 20 m at Chainage 710 m, 14 m at Chainage 760 m and 15 m at Chainage 800 m. This layer can also be observed at the depth of 57.5 m at Chainage 850 m, 45 m at Chainage 900 m and 15 m at Chainage 960 m.

Second layer with resistivity value of 60 Ωm-200 Ωm indicates presence of saturated silt, sand and gravel from Chainage 230 m to 840 m of the profile. The thickness of this layer is 52 m at Chainage 320 m, 60 m at Chainage 300 m, 57 m at Chainage 480 m, 10 m at Chainage 640 m, 57 m at Chainage 540 m, 20 m at Chainage 710 m, 27.5 m at Chainage 770 m and 32 m at Chainage 800 m.

Third layer with resistivity ranging from 200 Ωm–350 Ωm indicates presence of saturated sand and gravel from the Chainage 200 m to 840 m. The thickness of this layer is 15 m at Chainage 250 m, 30 m at Chainage 320 m, 32 m at Chainage 400 m and 30 m at Chainage 480 m. This layer can be also observed at the depth of 42 m at Chainage 580 m, 23 m at Chainage 640 m, 37 m at Chainage 700 m and 47 m at Chainage 800 m.

The last layer with resistivity value ranging from 360 Ωm–640 Ωm indicates presence of highly compacted sediment/ gravel with medium to large boulders from Chainage 130 m to 565 m. This layer can be observed at the depth of 40 m at Chainage 160 m, 37 m at Chainage 250 m, 100 m at Chainage 320 m, 105 m at Chainage 400 m, 107 m at Chainage 480 m and 120 m at Chainage 560 m.

DEEP TUBEWELL (DTW) CONSTRUCTION

Based on VES and ERT interpretations, five deep tubewells were constructed at Kalimati, Ranitar, Khaharephant, two DTWs at Chyanglitar and two others deep tube tubewell were constructed at the Harrabot and Garambesi .5 l/s, 8 l/s, 4 l/s, 3.33 l/s, 13.8 l/s and 7.7 l/s, 6.8 l/s discharge were observed at Harrabot, Kalimati, Garambesi, Ranitar, Khaharephant and Chyanglitar areas respectively. Table 5 provides the detail information regarding these seven deep tubewells (DTWs) and lithlogs of different tubewells are shown in Figure 18.

The pumping test was carried out by Constant-Rate Test. From the constant rate we obtain value of transmissivity, hydraulic conductivity and specific capacity using semi-log graph (time-drawdown graphs) and Cooper-Jacob method (Table 6).

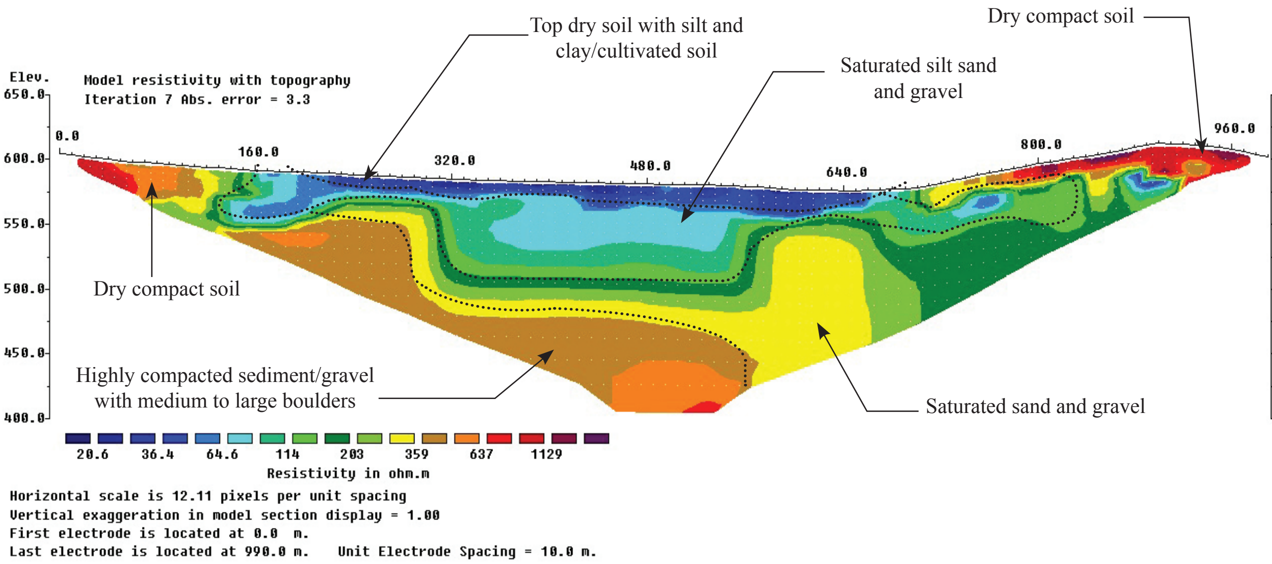

Fig. 17: Interprepative resistivity Tomogram of ERT-3, Ranitar, Palungtar Municipality, Gorkha.

DISCUSSIONS

Detailed hydrogeological study has been carried out by direct and indirect hydro geophysical and hydrogeological methods. Indirect methods includes VES and ERT surveys and direct method includes drilling investigation tube wells and regional geological study. The lithology expected by VES and ERT interpretation was compared with drilled samples which were found coherent with lithology but was varying at depth. These fractured bed rocks can be a great source of groundwater in hilly areas. The comparative chart is shown in tables 7,8,9,10.

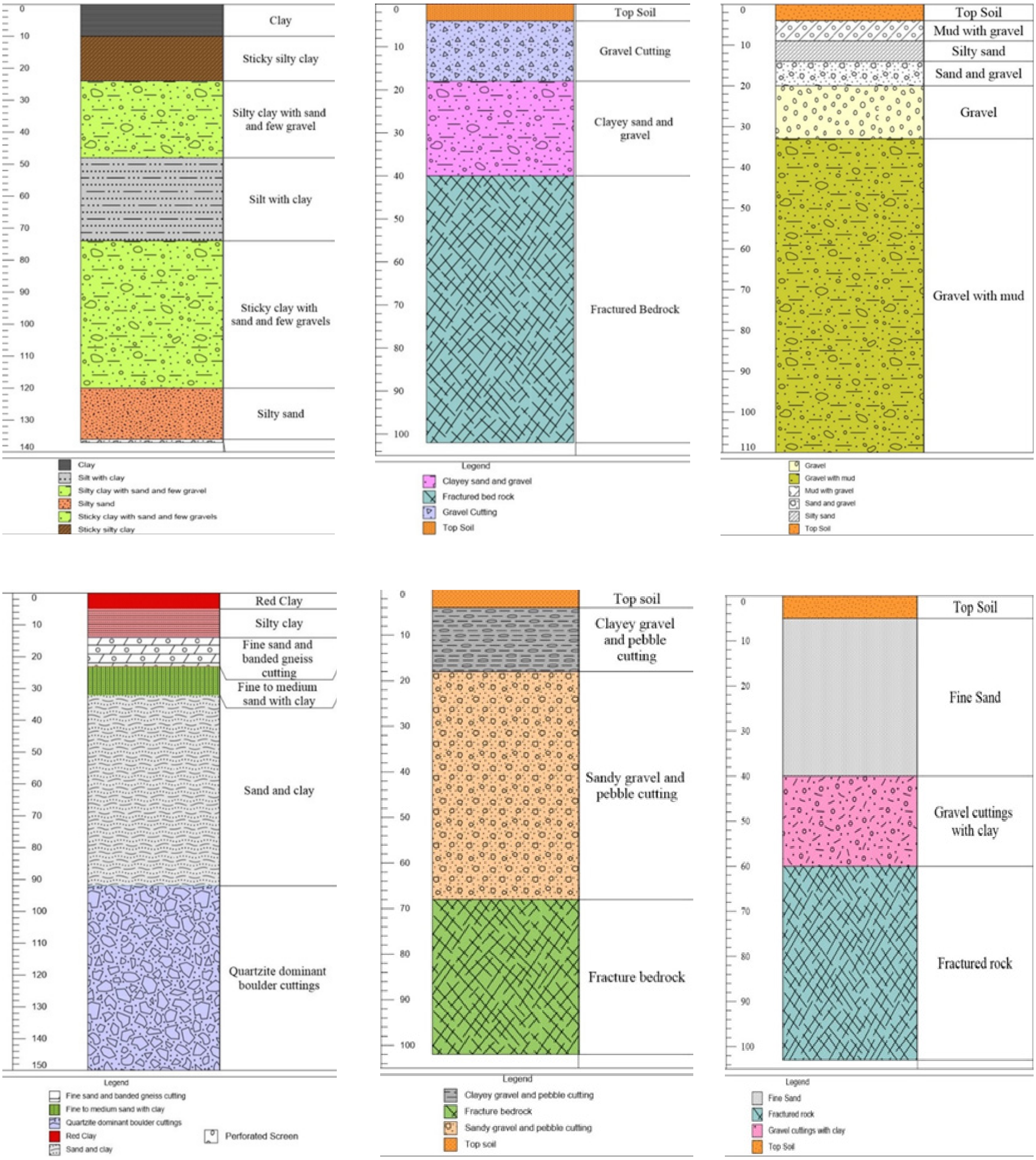

Fig. 18: Litholog of seven different tubewells obtained during drilling starting from Harrabot, Kalimati, Garambesi, Ranitar, Khaharephant and Chyanglitar (DTW-1 and DTW-2) respectively, while going from north to south direction.

Table 5: Details about seven (8"/6") Deep Tubewells.

Location	Latitude	Longitude	Drilled depth (m)	Screen type	Total screen length (m)	Drilling method
Harrabot, Lamjung	28°6'53.20"N	84°26'21.63 E	137	Perforated	48	DTH
Kalimati, Tanahu	28.0934° N	84.4415° E	102.5	Perforated	30	DTH
Garambesi, Lamjung	28°4'8.94" N	84°28'50.63" E	123	Perforated	111	DTH
Ranitar, Gorkha	28°2'45.79"N	84°29'16.04 E	150	Perforated	35	DTH
Khaharephant, Tanahu	28.01144° N	84.44998° E	102.5	Perforated	30	DTH
Chyanglitar, Gorkha (DTW 1)	27.95315° N	84.43159° E	103	Perforated	45	DTH
Chyanglitar, Gorkha (DTW 2)	27°58'35.6" N	84°26'51.1" E	123	Perforated	94	DTH

Table 6: Pumping test results.

Parameter	Harrabot	Kalimati	Garambesi	Ranitar, Palungtar	Khaharephant	Chyanglitar, Gorkha (DTW1)	Chyanglitar, Gorkha (DTW2)
Discharge (l/s)	5	8	4	3.33	13.8	7.7	6.7
SWL (m)	60	8.50	44.9	92.3	17.45	28	0. 00
DWL (m)	78	42.67	55	94.11	18.05	40.30	42.46
Transmissivity (m^2/day)	4.395	3.7	39.53	29.1	363.89	9.9	13.22

Table 7: Comparative lithological projection by VES and observed litholog samples from Chyangli area.

Layer s	VES -3				Observed litholog		
	Resistivity [Ohm-m]	Thickness (m)	Depth (m, bgl)	Expected lithology	Depth (m, bgl)	Thickness (m)	Lithology
1	228.2	1.40	1.40	Topsoil	12	12.00	Red clay
2	136	31.55	32.95	Fine Sand	36	24.00	Black clay with sand
3	353.7	17.46	50.41	Coarse Sand Gravel	72	36.00	Gravel with medium sand
4	64.78	61.42	111.8	Silt, Fine Sand	96	23.00	Angular gravels of Meta-sandstone with sand
5	1301	-	-	Fresh Rock	103	7.00	Moderately weathered phyllite

Table 8: Comparative lithological projection by ERT and observed litholog sample observed from tubewells at Kalimati area.

Layers	ERT-1 (Chainage 200 m)			Litholog samples observed from Tubewells		
	Resistivity [Ohm-m]	Thickness (m)	Expected lithology	Depth (m)	Thickness (m)	Lithology
1	81.4-124	5	Top dry soil with clay/silty clay	0–2	2	Top soil
2	69.2-1462	15	Silty sand with clay	2–18	16	Alluvial Pebbles and gravels cuttings
3	124-188	40	Saturated medium to coarse sand and gravel	18–40	22	Sand, clayey gravel and pebble cuttings
4	188-286	30	Saturated sand and gravel	40–68	28	Fractured rock
5	−	−	−	68–102	34	Fractured rock/Bed rock

Table 9: Comparative lithological projection by ERT and observed litholog sample observed from tubewells at Khaharephant area.

Layer	ERT-5 (at Chainage 200 m)			Litholog samples observed from tubewell		
	Resistivity [Ohm-m]	Thickness (m)	Expected lithology	Depth (m)	Thickness (m)	Lithology
1	83.1	5	Top dry soil with Clay/silty clay	0–3	3	Top soil
2	147	15	Saturated sand and gravel	3–18	15	Clayey Pebbles and gravels cuttings
3	124–188	45	Saturated medium to course Sand and gravel	18–68	50	Sand, clayey gravel and pebble cuttings
4	147	37	Saturated sand and gravel	68–102	34	Fractured rock /Bed Rock

Table 10: Comparative lithological projection by ERT and observed litholog sample observed from tubewells at Ranitar area.

Layer	ERT-3 (at Chainage 200 m)			Litholog samples observed from tubewell		
	Resistivity [Ohm-m]	Thickness (m)	Expected lithology	Depth (m)	Thickness (m)	Lithology
1	40.2	15	Top dry soil with clay/silty clay	0–5	5	Red clay
2				5–14	9	Silty clay
3	79.4	35	Saturated silt, sand and gravel	14–23	9	Find sand with gravel cuttings
4				23–32	9	Fine to medium sand with clay
5	40.2–56.5	50	Clay mixed with sand and gravel	32–92	60	Sand with clay
6	157–220	50	Highly compacted sediment/ gravel with medium to large boulders	92–150	58	Boulders cuttings of quartzite

CONCLUSION AND RECOMMENDATION

The hydrogeological condition of seven different areas along the Marsyangdi River has been carried out using the geophysical and drilling results. As there has been little systematic studies on groundwater within the middle hills, it is difficult to evaluate and discuss the results. So, this study is solely based upon our experiences and studies based on deep tubewell construction along Marsyangdi River terraces. Geologically, the project sites are located in the Ranimatta Formation of Lesser Himalaya composed of phyllite, phyllitic metasandstone, gritty phyllite, and quartzite. This has resulted that the appearance of groundwater in hilly regions is highly controlled by geology and geological structures. The hydrogeological condition of the area was analyzed by geological, geomorphological, Google imageries and geophysical survey in Harrabot, Kalimati, Garambesi, Ranitar, Khaharephant and Chyanglitar. While going from north (Harrabot) to south (Chanyanglitar) covering around the distance of 25km, the discharge and transmissivity varies. At the northern areas, groundwater potential is medium (5.8) lps, poor at middle areas (4, 3.33) lps and medium to good potential at the southern areas (13.8, 7.7, 6.7) lps and an artesian well is developed at southern area (DTW2 at Chyanglitar).

Mainly based on geophysical survey, seven sites were selected and deep tubewells were constructed. Based upon the geophysical and deep tubewell construction in these areas, the areas around Marsyangdi river shows medium to good potential for groundwater and these groundwater can be extracted for irrigation and other purposes. After this successful deep tubewell construction in hilly region, we can conclude that the ERT and VES method of geophysical investigation can be a reliable method for groundwater exploration around the Marsyangdi river terraces.

Lithology obtained by electrical resistivity data and litholog samples during drilling which were quite relevant with each other revealed that the area consists of alluvials deposits of Marsyangdi River and fractured to fresh rock composed of phyllite and metasandstone. In these areas the aquifer lies on pebbles, gravels and sand of alluvial deposits and fractured bedrock. Sources of recharge for groundwater around the area could be infiltration of rainfall and Marsyangdi River and its tributaries. After this detailed study, we can conclude that the appearance of groundwater in hilly regions is highly controlled by geology and geological structures. Likewise, other part of Marsyangdi River terraces comprising similar geology and geomorphology suggests that the area is rich in groundwater potential. The methods and techniques used in the present study can be replicated in other river terraces and mid hills of Nepal for estimation of groundwater potential.

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