Report on

Geophysical Study (Vertical Electric Sounding - VES)

at

Doti District

<u>Submitted to</u>

Sudurpaschim Provincial Government

Ministry of Physical Infrastructure Development

Water Resources and Irrigation Development Division Office

Rajpur, Doti

<u>Submitted by</u>

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1. INTRODUCTION

1.1 Background

Ground water is one of natural resources that serve to support life and development activities. Until now, groundwater is still the main source to meet the water needs for the population, both for drinking water, households, irrigation water and industrial water, so that groundwater is a natural wealth that fulfills the livelihood of many people. This resource can be extracted from the subsurface aquifer all around the year for purposes like irrigation, industry, drinking water etc. These aquifers get recharged during the monsoon period from infiltration of rain water. This renewed resource (groundwater) can again be used during the next season; and cycle goes on every year. Unlike surface water, it can also be exploited at or nearby the place of use and can be used only when necessity is felt. Short drought does not affect groundwater supply seriously like the surface water. Hence it can be a very good source for regular and reliable supply of water. Due to these advantages, groundwater is being used widely for various purposes.

Groundwater is the water present beneath Earth's surface in soil pore spaces and in the fractures of rock formations. It is stored in and moves slowly through geologic formations of soil, sand and rocks called aquifers. It gets completely saturated with voids of rock at the depth of soil pores spaces or fractures and forms water table. Ground water recharge or deep drainage is hydrologic process where water moves downward from surface water to groundwater.

An aquifer is a layer of relatively porous substrate that contains and transmits groundwater. When water can flow directly between the surface and saturated zone of an aquifer then the aquifer is unconfined. The deep parts of unconfined aquifers are generally more saturated since gravity causes the water to flow downwards. The upper levels of this saturated layer of an unconfined aquifer are known as the water table or phreatic surface. Below the water table, where generally all the pore spaces are saturated with water is called the phreatic zone. Substrate with relatively low porosity that permits limited transmission of groundwater is called an aquitard. An aquiclude is a substrate with porosity which is so low it is virtually impermeable to the groundwater. A confined aquifer is that aquifer which is overlain by a relatively impermeable layer of a rock or a substrate such as an aquiclude or aquitard. If a confined aquifer is following a downward grade from its recharge zone, then the groundwater can become pressurized as it flows. This usually creates artesian wells which flow freely without the need of any pump and rise to a higher level than the static water table at the above unconfined aquifer. The properties of aquifers vary with the geology and the structure of the substrate and the topography in which they occur. Usually, the more productive aquifers are found in the sedimentary geologic formations. Relatively, the weathered and the fractured crystalline rocks yield smaller amount of groundwater in most of the environments. Unconsolidated poor cemented alluvial materials that have aggregated as valley-filling sediments in the major river valleys and the geologically subsiding structural basins are included among the most productive sources of groundwater.

Groundwater is not found everywhere. Lithological layers consisting of coarse grains of 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 or aquifer. Such layers may contain water in them but cannot move from them easily due to 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. Hence to increase the chance of success of groundwater exploitation (Drilling), a prior study employing suitable scientific method is to be conducted in the area under consideration. Due to these advantages, groundwater is being used widely for various purposes. Since the demand of groundwater increases with population growth, it is necessary to explore groundwater more intensively adequately and accurately. There are many geophysical methods, which plays a vital role in the exploration of groundwater. One of the best and reliable geophysical methods for the groundwater study is Electrical Resistivity method. This method is very useful to understand the hidden subsurface hydrogeological condition.

For the assessment of hydro-geological condition of the proposed drilling area before drilling, Geophysical Method (Vertical Electrical Sounding) is desirable and for this purpose geophysical survey, Vertical Electrical Sounding (VES) is carried out at three different points. The locations of the study area for VES point was proposed in three different location of Doti district which is given below along with its geographical coordinates:

1. 29°15'10.702''N and 80°54'01.338''E, Dipayal Silgadi Municipality, Doti
2. 29°15'36''N and 80°56'3''E, Dipayal Silgadi Municipality -03, Doti

Doti is a district located in the far-western region of Nepal. Access to safe drinking water in Doti district is still a major challenge for many of its residents. The district is largely mountainous, with difficult terrain and limited water sources, which makes it challenging to provide water for the irrigation purpose. The main sources of water in Doti are springs, streams, and wells.

To address this issue, various government and non-governmental organizations have been working to improve access of water for irrigation in Doti. Development of sump well and distribution of water through the canal is the main aim of the Water Resource and Irrigation Development Office of Doti District. To know the water table, this geophysical survey was carried out. Further, sump well will be constructed and water will be distributed through the canal to the farmers for the irrigation.

1.2 Field Visit Program

The field visit program for the Geophysical Survey was conducted by the team of comprising of Hydro-geologist, Geo-physicist, Technical Assistants and local labors. Overall, the field visit program provided the raw data which by further processing helped in deeper understanding of the field and the tools used in it.

A field visit program for geophysical survey typically includes the following steps

1. Planning: the first step is to plan the field visit program. This includes identifying the objectives of the survey, selecting the appropriate geophysical method to use and determined the area to be surveyed.
2. Equipment: once the planning is complete, the next step is to ensure that all necessary equipment is available and in good working condition. This includes geophysical instruments, surveying equipment, safety equipment, and any other necessary tools

3. Site preparation: before the survey can begin, the site need to be prepared, this may involve clearing vegetation, removing debris, marking out the survey area, and setting up any necessary equipment such as GPS receivers.
4. Surveying: the survey phase involves collecting geophysical data using selected method. For the ground water exploration the method is applied i.e. VES and ERT.
   For this project we applied Vertical Electrical Sounding (VES)

1.3 Location and Accessibility

The study area is located in, Doti district. The area is accessible by black topped Mahakali Highway Road up to Syauli Bazar from Attariya, Kailali District and about 32 km by K.I. Singh highway towards the study area

Doti district is located in the far-western region of Nepal, which is a relatively remote and mountainous area. Despite this, the district is still accessible by various modes of transportation. The main means of transportation to Doti district are buses and jeeps, which are available from Kathmandu, Nepalgunj, and other major cities in Nepal. The journey by road can be challenging due to the difficult terrain, but the roads are generally in fair condition.

The nearest airport to Doti district is the Dhangadhi Airport, which is located about 132 kilometers to the south. From there, you can take a taxi or bus to reach Doti. In terms of location, Doti is situated in a strategic location, with India to the south and west, and the other districts of the far-western region of Nepal to the east. This location makes it an important hub for trade and commerce in the region.

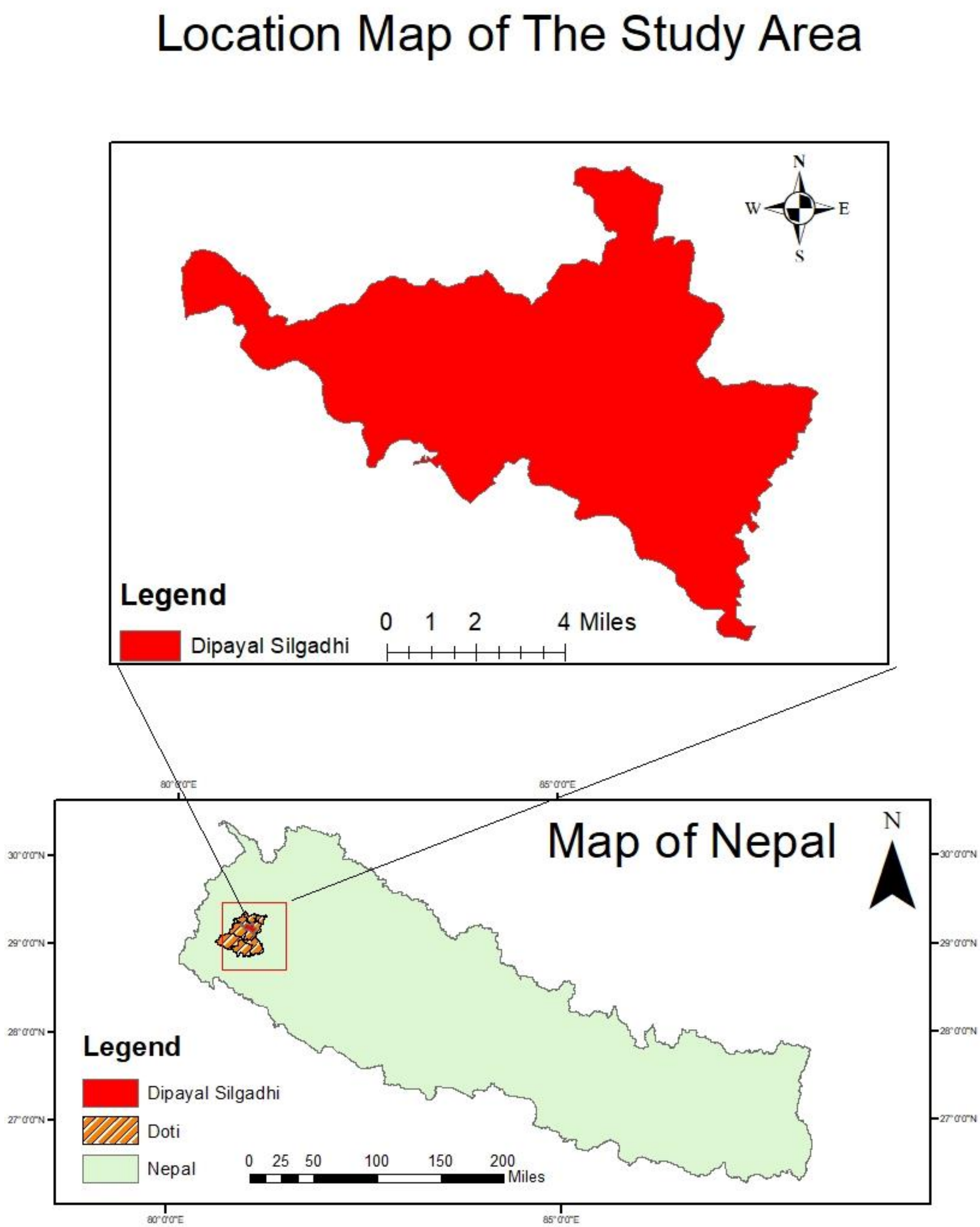

Figure 1: Map of Nepal Showing Study Area

Figure 2: Google Earth Image of the Study Area

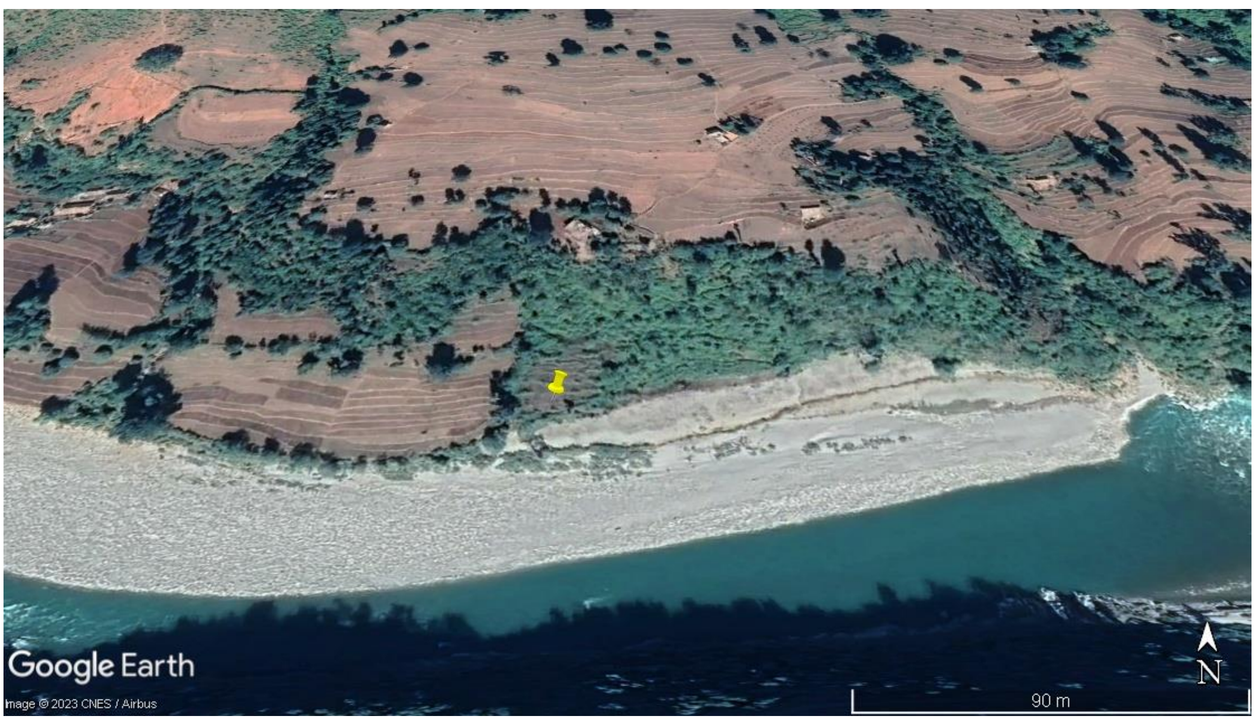

Figure 3: VES point Shown on Google Earth

Figure 4: VES point Shown on Google Earth

1.4 Topography and Drainage

Topography refers to the physical features of the surface of the earth, including its elevation, slope and shape. It can be described as the study of the shape and features of land surface. Topography can affect the flow of water across the land.

Drainage refers to the process of removing excess water from an area. This is important to prevent flooding which can damage crops, building and infrastructure. Drainage systems can be nature such as river and stream or man-made, such as ditches, pipe and culverts.

Doti district is located in the far-western region of Nepal and is characterized by diverse topography and drainage patterns. The district covers an area of 2,025 square kilometres and is mostly hilly and mountainous. The southern part of the district consists of a narrow valley along the Seti River, which is the main river in the district. The Seti River originates from the Mahabharat Range in the south and flows through the district before eventually joining the Karnali River in

Bardia district. The central part of the district is marked by high ridges and valleys, with elevations ranging from 1,500 meters to 2,500 meters above sea level. This area is characterized by steep slopes and is prone to landslides, especially during the monsoon season. The northern part of the district is characterized by high mountains and is home to the Api Nampa Conservation Area. The highest peak in the district is Api Himal, which has an elevation of 7,132 meters above sea level.

The drainage pattern in Doti district is mainly dendritic, with small tributaries feeding into the Seti River. The district is also home to several small streams and springs, which provide water for drinking and irrigation purposes. Overall, the topography and drainage of Doti district make it a unique and diverse area, with challenges and opportunities for agriculture, tourism, and other economic activities.

1.5 Scope and Objective

The main objective of the present study was to know the subsurface hydrogeological condition of the study area for the exploration of groundwater. This resource will be used for fulfilling the demand of water for household use. To fulfill this objective, Geophysical Survey (Electrical Resistivity Survey, Vertical Electrical Sounding) was carried out in the proposed study area. The main aim of conducting Electrical Resistivity Survey was to find out the subsurface geological features related to water bearing zones (aquifer) for the extraction of reasonable volume of water and to find out drilling location and depth for the exploitation of ground water resource.

To meet the specific objectives, the scopes of work are as follows:

- Carry out Electrical Resistivity Survey (Vertical Electrical Sounding)
- Compute, analyze and interpret VES data with computer added software.
- Make suggestion and recommendations on hydrogeological condition on the basis of VES interpretation, geological and geomorphological observations.
- Report Preparation

1.6 Approach and methodology

The methodology of the study consisted of materials collection; literature collection and review, field planning, geological observation and geophysical (VES) survey, data computation, processing and interpretation; and finally report preparation.

1.6.1 Desk Study and Field Planning

Necessary materials for the site visit like VES instrument with accessories (Ground Resistivity Meter, GD-10), District Map, GPS (Global Positioning System), Photographic Camera, Brunton Compass etc. were used. The general geology of the area is taken from the geological map of the area prepared by Department of Mines and Geology. The description of the geology of the area is adopted from the published and unpublished literatures and verified in the field by observation and field measurement.

1.6.2 Fieldwork and Data Acquisition

In VES survey, Schlumberger configuration was used to obtain the resistance of ground surface. The electrodes were expanded up to desire length on either side of the sounding point (AB/2). The readings were taken with potential electrode spacing 1, 5, 15 and 50 m with current electrode spacing up to desire length (AB/2). For data acquisition, Geomative (GD-10 Series of Geo-electrical System) Resistivity Meter, insulated cable of several hundred meters wound on portable reels, four steel electrodes were used. During the data acquisition, sudden topographic variations and possible source of noise like electric high voltage lines, buried pipe lines are generally avoided. GPS was used to record the position of sounding point, measuring tape was used to measure the spacing of the electrodes and compass was used to measure the orientation of sounding line. Photographs were taken to characterize the topographical and morphological features of the area. Apparent resistivity was plotted against electrode spacing (AB/2) on semi-transparent log-log paper to check the consistency of the acquired data.

1.6.3 Data Processing, Interpretation and Report Preparation

The acquired field data were computed on spreadsheet and plotted. Computer added program res1d.exe was used for data analysis and interpretation. It is designed for automated and interactive semi-automated interpreting of vertical electric sounding.

1.7 Expected Outcome of the Study

The Expected outputs of the Geophysical Survey (VES) are as follows:

- Detailed VES survey of selected area.
- Comprehensive discussion, analysis and interpretation of VES data.
- Comprehensive report of the study with maps and photographs

2. GEOLOGY AND HYDROGEOLOGY OF THE STUDY AREA

2.1 Regional Geology of the Nepal

Geologically, Nepal occupies the central sector of Himalayan arc. Nearly one third of the 2400 km long Himalayan range lies within Nepal. It is divided into following five major subdivisions from south to north, respectively:

1. Terai (Indo-Gangetic plain)

2. Sub-Himalaya (Siwalik)

3. Lesser Himalaya

4. Higher Himalaya

5. Tibetan-Tethys zone

2.1.1Terai zone

Terai represents the northern edge of the Indo-Gangetic alluvial basin and belongs to the southernmost tectonic division of the Nepal. In the north it is bounded by the Main Frontal Thrust (MFT). The Terai plain is made up of alluvium of Pleistocene to recent age with an average thickness of 1500 m. The Terai is already sharing a significant proportion of current Himalayan stress accumulation, which is manifested in the development of blind thrusts, and thrust propagated folds beneath the sediments.

2.1.2 Sub-Himalayan (Churia/Siwalik) zone

Sub Himalayan zone is bounded to the south by Main Frontal Thrust (MFT) and to the north by Main Boundary Thrust (MBT). The Sub-Himalayan Zone consists basically of the rocks of fluvial origin belonging to the Neogene age. The lower Siwalik consists of finely laminated sandstone, siltstones and mudstones and the thickness of the unit is more than 2000 m. The middle Siwalik are is made up of medium to coarse grained salt and pepper type sandstone and its thickness is about 3000 m. The upper Siwalik comprises of conglomerate and boulder beds of thickness of more than 1000 m. The Dun valleys within the Siwalik are covered by Quaternary fluvial sediments.

2.1.3 Lesser Himalaya

The Lesser Himalayan Zone is bordered in the south by MBT and in the north by the MCT. The lesser Himalayan rocks throughout the Himalaya consists of two sequences: allochthonous and autochthonous to para-autochthonous. The MBT has brought the older Lesser Himalayan rocks over the much younger Siwalik. This zone is made up mostly of the unfossiliferous sedimentary and metasedimentary rocks like slate, phyllite, schist, quartzite, limestone, dolomite etc. ranging in age from Precambrian to Eocene (Upreti, 2000).

2.1.4 Higher Himalaya

Higher Himalayan Zone has been mapped and traced along the entire Himalayan region and has been named differently in different places. Geologically, the Higher Himalayan Zone includes the rocks lying to the north of MCT and below the fossiliferous Tibetan-Tethys Zone.

The upper limit of this zone is generally marked by normal faults. This zone consists of about 10 km thick succession of crystalline rocks also known as Tibetan Slab (Le Fort 1975). The crystalline units of the Higher Himalaya extend continuously along the entire length of the country. The high-grade kyanite-sillimanite bearing gneiss, schist, marble of the zone forms the basement of the Tibetan-Tethys Zone. Tertiary granites occur at the upper part of the Tibetan-Tethys sedimentary rocks.

2.1.5 Tibetan-Tethys Himalaya

The Tibetan-Tethys Zone begins from the top of the Higher Himalaya and extends to the north in Tibet. In Nepal, the fossiliferous rocks of this zone are well developed in the ThakKhola (Mustang), Manang and Dolpa. Most of the great Himalayan Peaks of Nepal including Mt.Everest, Manaslu, Annapurna and Dhawalagiri belong to this zone. This zone is composed of sedimentary rocks such as shale, limestone and sandstone ranging in age from Lower Paleozoic to Paleogene.

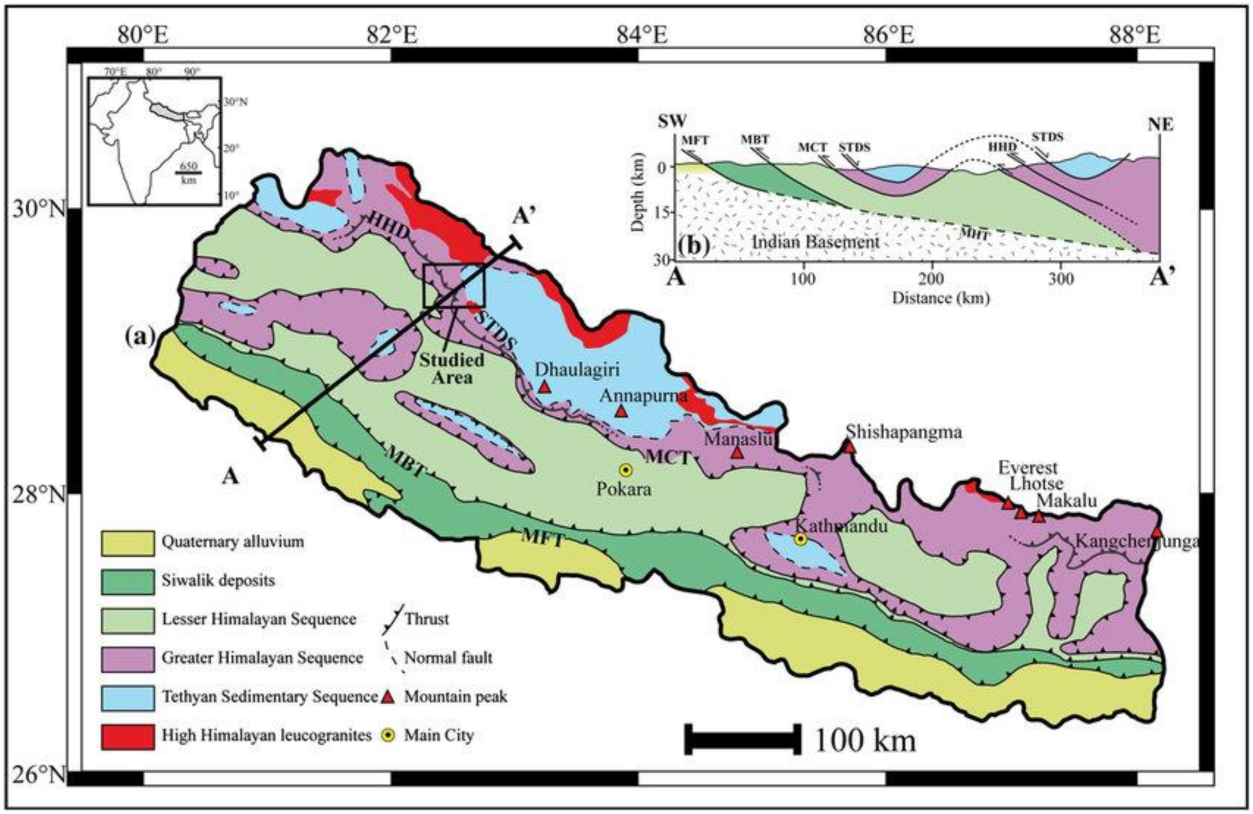

Figure 5: Geological map of Nepal Himalaya, an outline of regional geology

Table 1: Tectonic Zones of the Nepal Himalaya along with their tectonic structures

Terai	MFT	Sub Himalaya	MBT	Lesser Himalaya	MCT	Higher Himalaya		Tibetan Himalaya	Geomorphological Division
Ganges Alluvium		Siwaliks Sedimnets		Lesser Himalaya Sediments		Higher Himalaya Gneiss	Tethys Sediments		Geologcal Division

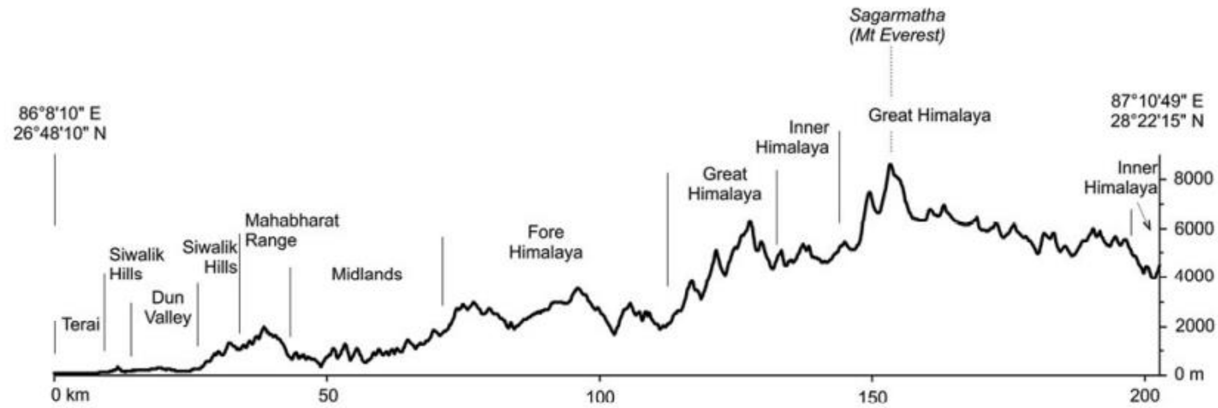

Figure 6: Profile of the Himalaya from east Nepal and position of physiographic regions

General Geology of the Study Area

The project area consists of varied lithology, the location lies on the lesser Himalayan. The location consists of schist, quartzite and gneiss along with parting of phyllite. Some of the locations lie on the alluvial deposit and colluvial deposit. The study area comprises of slightly to highly weathered gneiss along with the quartz parting and large quartz vein in the bed rock.

3. GEOPHYSICAL SURVEY

3.1 General

Geophysical methods have wide range of its applicability in locating or tracing an object of interest as suggested by the geophysical response of the object. Detectability of the body depends on the size and distance or depth at which the object occurs. The contrast in physical properties between the body and its surroundings also influences the detectability. There are four main geophysical methods viz. gravity, magnetic, seismic, and electrical (self-potential, electromagnetic, resistivity, induced polarization and well logging) out of which the electrical methods are the most suitable in ground water exploration and management. This is because the electrical properties, especially the resistivity of geological formations, vary significantly between their dry and saturated state which helps in identifying the aquifers.

3.2 Methodology

3.2.1 Electrical Resistivity Principle and Resistivity of Rocks

The resistivity survey is carried out by injecting DC current into the ground through two current electrodes, and measuring the resulting voltage differences at two potential electrodes. For the current value (I) and the observed voltage difference value (V), an apparent resistivity value (ρ_a) is calculated as follows.

$$(\rho_a) = k\ V/I$$

Where, k is the geometrical factor which depends on the arrangement of the four electrodes.

The calculated value (ρ_a) is not the true resistivity of the sub-surface materials. An "apparent resistivity" value of a homogeneous ground will give the same resistance value for the same electrode arrangement. The relationship between the apparent resistivity and the "true" resistivity is a complex relationship. In fact, an inversion of the measured apparent resistivity values using a computer program is necessary to determine the true sub-surface resistivity.

Electrical resistivity of the rocks or sediments depends on the resistivity of their mineral matrix and the fluid contained in its pore spaces. The electrical resistivity of the soil can be considered as a proxy for the variety of soil physical properties. Electrical resistivity is a function of a number of soil properties, including the nature of the solid constituents (particle size distribution, mineralogy), arrangement of voids (porosity, pore size distribution, connectivity), the degree of water saturation (water content), electrical resistivity of the fluid (solute concentration) and temperature.

Rocks are composed primarily of quartz, feldspar and mica or other silicate minerals, which are poor conductors. They contain water in the pores, which is usually a better conductor. Thus the resistivity of, say, sandstone, generally depends on geometry of its pore spaces and the resistivity (or salinity) of its contained fluid. As permeability and porosity decrease, resistivity usually increases, when there is no change in formation fluid. The resistivity also depends upon the age of the rock or sediment as, with age, they become compacted and/or weathered. Compacted rocks show very high resistivity compared to unconsolidated sediments like clays, sands, gravels and so on as there will be less fluid in it. The weathered rock shows low resistivity when there is presence of water in it. Dry rocks or sediments have very high resistivity (of the order of 10,000 to 100,000 Ohm-m), whereas water bearing rocks or saturated sediments become much less resistant (10 to 1,000 Ohm-m).

All rocks contain some pores in them. Under any reasonable circumstances, these pores are partly or completely filled with water. This water usually carries some salt in solution so that the water content of rock has a far greater capacity for transmitting current than does the solid matrix of the rock unless highly conducting minerals are present.

In some rocks, such as consolidated sedimentary rocks, porosity is inter granular in nature consisting of the spaces left over after the rock grains were compacted. In other rocks and particularly in igneous rocks, porosity occurs primarily in the form of joints.

In general, hard rocks are poor conductors of electricity, but geological processes like weathering, dissolution, hydrothermal alteration; faulting and shearing can alter rock to increase the porosity and permeability of rock and hence decreases resistivity. By comparison, compaction of sedimentary rock and metamorphism of all types may result in lower porosities and permeability. Resistivity is, therefore, a widely varying parameter, which changes not only from lithology to lithology, but also within a particular formation of same lithology.

Alluvium is a broad term referring to all unconsolidated material formed in recent geological time under conditions other than subaqueous. Classic rock such as sand and gravel are classified by geologist according to size, sorting and distribution of particles as well as the chemical content of silica, feldspar and calcite. Sand is defined with particle diameters ranges from 0.0625 mm to 2 mm. Gravel is defined with particle diameters ranging from 2mm to an excess of 256 mm. Sand and gravel are defined as continuously graded unconsolidated materials (sediments) formed as a result of the natural disintegration of rocks. These unconsolidated sand and gravel have good infiltration and higher ground water permeability, so they are good source of ground water.

Table 2: Wentworth (1922) grain size classification

Millimeters (mm)		Micrometers (µm)	Phi (ϕ)	Wentworth size class	
	4096		-12.0	Boulder	Gravel
	256		-8.0	Cobble	
	64		-6.0	Pebble	
	4		-2.0	Granule	
	2.00		-1.0	Very coarse sand	Sand
	1.00		0.0	Coarse sand	
1/2	0.50	500	1.0	Medium sand	
1/4	0.25	250	2.0	Fine sand	
1/8	0.125	125	3.0	Very fine sand	
1/16	0.0625	63	4.0	Coarse silt	Silt
1/32	0.031	31	5.0	Medium silt	
1/64	0.0156	15.6	6.0	Fine silt	
1/128	0.0078	7.8	7.0	Very fine silt	
1/256	0.0039	3.9	8.0	Clay	Mud
	0.00006	0.06	14.0		

The electrical properties and physical behavior of sand and gravel deposits depend significantly on moisture content of the materials. Dry sand and gravel deposit have a high electrical resistivity whereas saturated sand and fine gravel deposit have a much lower resistivity value and can be further influenced by the presence of salinity. The responses of the electric current with response to grain size, (sand, gravel, pebble, boulder, clay, silt fractured weathered rocks, bedrock. etc. are the basis for the method to identify potential areas for ground water extraction. Coarse sediments (sand, gravel, pebble, boulders layer), fractured /weathered bedrocks mainly limestone, sandstone etc. usually have better potential for groundwater storage compared to fine sediments like clay, silt, sandy clay, clay with gravels, competent bedrock like quartzite, gneiss, biotite, schist etc. Resistivity is a widely varying parameter, which changes not only from lithology to lithology, but also within a particular stratum of same formation.

Table 3:Electrical Resistivity versus Lithology (After Palaky 1987)

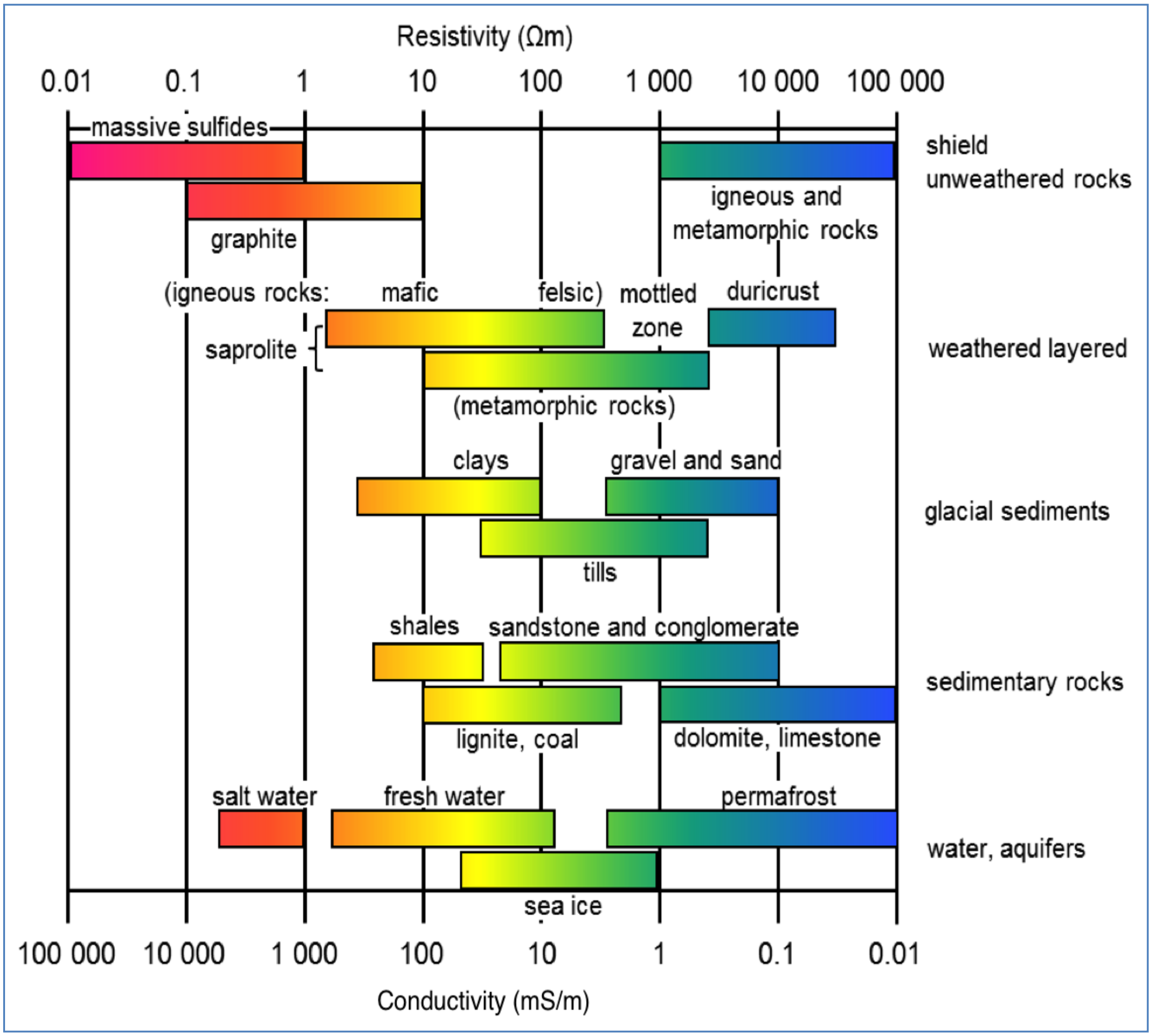

Table 4: Resistivity of common geologic materials (Source: Reynolds, 1997)

Materials	Normal Resistivity (Ωm)	Materials	Normal Resistivity (Ωm)
Granite	3×10^2-10^6	Alluvium and sand	10-8×10^2
Syenite	10^2-10^6	Morine	10-5×10^3

Diorite	10^4-10^5	Gravel(Dry)	1400
Gabbro	10^3-10^6	Gravel(Saturated)	100
Basalt	10-1.3 x 10^7	Quatenary/Recent sands	50-100
Schist(graphite)	10-10^2	Ash	4
Slates	6 x 10^2-4 x 10^7	Laterite	8000-1500
Marble	10^2-2.5 x 10^8	Lateritic soil	120-750
Quartzite	10 -2 x 10^8	Dry sandy soil	80-1050
Consolidated Shale	20-2 x 10^3	Sandy clay/Clayey sand	30-215
Conglomerates	2 x 10^3-10^4	Sand and gravel	30-225
Sandstones	1-7.4 x 10^8	Unsaturated landfill	30-100
Limestone	50-10^7	Saturated landfill	15-30
Dolomite	3.5 x 10^2-5 x 10^3	Glacier ice(temperate)	2 x10^6-1.2 x 10^8
Marls	3-70	Glacier ice(polar)	5 x 10^4-3 x 10^5
Clays	1-10^2	Permafrost	10^3- >10^4

Apparent resistivity values obtained in the field are not equal to the actual resistivity of the geologic units which affect the potential measured at the potential electrodes, unless measurements are being made over homogenous ground (Telford and others, 1990). At shallow exploration depth and at short current electrode spacing, shallow layers through which most of the current flows mostly influence measured apparent resistivity. As electrode spacing increases, a greater proportion of the induced current flows into deeper geologic layers, thus the response measured at the surface is reflective of the resistivity of increasingly deeper geologic units as the electrode spacing are increased. Hence as the distance between the current electrodes increases, so does the exploration depth or the depth of investigation of the survey

3.2.2 The relationship between Resistivity and Porosity

Naturally occurring groundwater commonly have high salinity and low resistivity. The resistivity of a rock decreases with increasing water content. In fully saturated rocks, the water content may be equated to the porosity, but in partially saturated rocks, the effect of de-saturation on resistivity must be considered. The texture of a rock also has some effect on the resistivity. One may obtain a theoretical expression for the relationship between resistivity and water content in a rock if a simple pore cemetery is assumed. Calculations of the resistivity of a matrix consisting of uniform spheres have been described many times in the literature. The most satisfactory relationship for the resistivity, ρt, of a fully saturated non-cemented rock consisting of equant grains is the following equation (Dakhnov, 1947 and 1948):

$$\rho_t = \frac{1+0.25(1-\phi)^{1/3}}{1-(1-\phi)^{2/3}}\rho_w = F\rho_w$$

Where, ρ_w is the resistivity of the water in the pores,

ϕ is the fractional porosity, and

F= is the formation factor, defined as the ratio of rock resistivity to the resistivity of the water contained in the rock.

Table 5: Values of the parameter a and m (Dakhnov, 1962)

Parameter	Values for different Rocks					
	Friable Sand	Weakly cemented sandstone	Normal sandstone	Friable Limestone	Limestone and coarsely crystalline dolomite	Dense limestone and dolomite
A	1	0.7	0.5	0.55	0.6	0.8
M	1.3	1.9	2.2	1.85	2.15	2.3

3.2.3 Electrical Resistivity Survey

In resistivity measurement, current flow tends to occur close to the surface. Current penetration can be increased by increasing separation of current electrodes. An electrode array is a configuration of electrodes used for measuring either an electric current or voltage. There are number of ways of setting up of current and potential electrodes, in the exploration of groundwater by electrical resistivity methods. The choice of an array and the distance between the electrodes is very important for obtaining the best possible information of the subsurface geology of a given area.

The method of survey in the present study is Vertical Electrical Sounding (VES). Vertical Electrical Sounding (VES) give an idea about the drilling depth for the exploitation of ground water resource

3.2.3.1 Vertical Electrical Sounding (VES) Survey

The method of survey used in the present study is the Vertical Geo electrical Sounding / Vertical Electrical Sounding using Schlumberger array of electrode configuration. This method is also called Electrical Drilling. This is the standard method used worldwide to assess the groundwater potential in a given area. This is an indirect method and gives general idea about the parameters like thickness and electrical resistivity of subsurface layer, which exists in the sounding point. This method gives the vertical variation in electrical resistivity due to different lithology present in survey area. Electrical resistivity is correlated to the sediment type (clay, silty clay, silty sand, sand, sand and gravel, fractured rock, bedrock etc.)

In this method, current is injected into the ground by using two current electrodes (A and B) which are made of steel and are driven into the ground. The current is produced with the help of DC battery and equipment with complicated integrated circuitry (resistivity equipment). The travelling current sets its path and amplitude into the ground, which depends upon the nature of underground. The underground lithology (type of earth material) play major role in this regard. The response is recorded in the equipment with the help of two measuring electrodes (M and N), which are also driven into the ground. The procedure is repeated to a number of times by taking the electrodes farther away successively in every steep and the response reading is recorded in the equipment. Farther the electrodes from the center point, the response is coming from the deeper part.

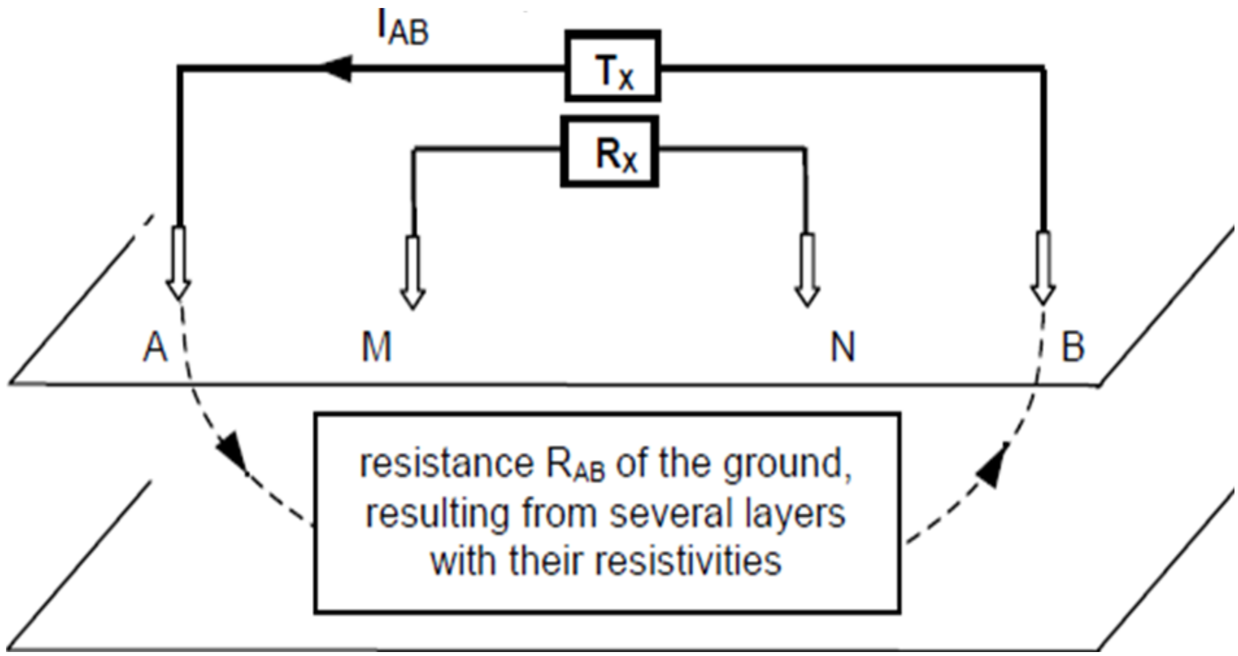

Figure 7: Vertical Electrical Sounding (VES)

3.3 Resistivity Measurement and Electrode Arrangement

In resistivity measurement, current flow tends to occur close to the surface. Current penetration can be increased by increasing separation of current electrodes. An electrode array is a configuration of electrodes used for measuring either an electric current or voltage. There are number of ways of setting up of current and potential electrodes, in the exploration of groundwater by electrical resistivity methods. The choice of an array and the distance between the electrodes is very important for obtaining the best possible information of the subsurface geology of a given area. Some of the common electrical arrays used for electrical resistivity exploration are as follows:

1. Wenner: The Wenner array consists of four collinear, equally spaced electrodes. The outer two electrodes are typically the current (source) electrodes and the inner two electrodes are the potential (receiver) electrodes. The array spacing expands about the array midpoint while maintaining an equivalent spacing between each electrode. The apparent resistivity is given by:

$$\rho a = 2\pi a \frac{V}{I}$$

2. Schlumberger: The Schlumberger array consists of four collinear electrodes. The outer two electrodes are current (source) electrodes and the inner two electrodes are the potential (receiver) electrodes. The potential electrodes are installed at the center of the electrode array with a small separation, typically less than one fifth of the spacing between the current electrodes. The current electrodes are increased to a greater separation during the survey while the potential electrodes remain in the same position until the observed voltage becomes too small to measure.
3. Dipole-dipole: The dipole-dipole electrode array consists of two sets of electrodes, the current (source) and potential (receiver) electrodes. A dipole is a paired electrode set with the electrodes located relatively close to one another; if the electrode pair is widely spaced it is referred to as a bipole. The convention for a dipole-dipole electrode array is to maintain an equal distance for both the current and the potential electrodes (spacing =a), with the distance between the current and potential electrodes as an integer multiple of a. The electrodes do not need to be located along a common survey line.

$$\rho a = \frac{V}{I}\pi a n(n+1)(n+2)$$

4. Square: Resistivity surveys have been performed using a square array of electrodes. The square array has been used for shallow environmental surveys, for assessment of joint orientation, and especially for archeological surveys. A dc-resistivity survey using the square-array method is conducted in a manner similar to that for traditional collinear arrays. The location of a measurement is assigned to the center point of the square. The array size (A) is the length of the side of the square. The array is expanded symmetrically about the center point, in increments of A(2)½ (Habberjam and Watkins, 1967), so that the sounding can be interpreted as a function of depth.

In practice, different electrode configurations have been adopted, the Schlumberger electrode configuration is used in this area. Because of this method in particular has a practical, operational, and interpretational advantage over the other methods. This is a four electrode symmetric system in which the inner electrodes (MN) are placed very close to each other and the distance between them is kept very small compared to current electrode distance (AB), usually less thean1/5th of the current electrode distance. The apparent resistivity values obtained with this array are attributed to the midpoint of the configuration, which is called the observation point 'O'. This configuration has been deployed in the study area.

The interpretation of the measurements can be performed based on the apparent resistivity values. The depth of investigation depends on the distance between the current electrodes. In order to obtain the apparent resistivity as the function of depth, the measurements for each position are performed with several different distances between current electrodes.

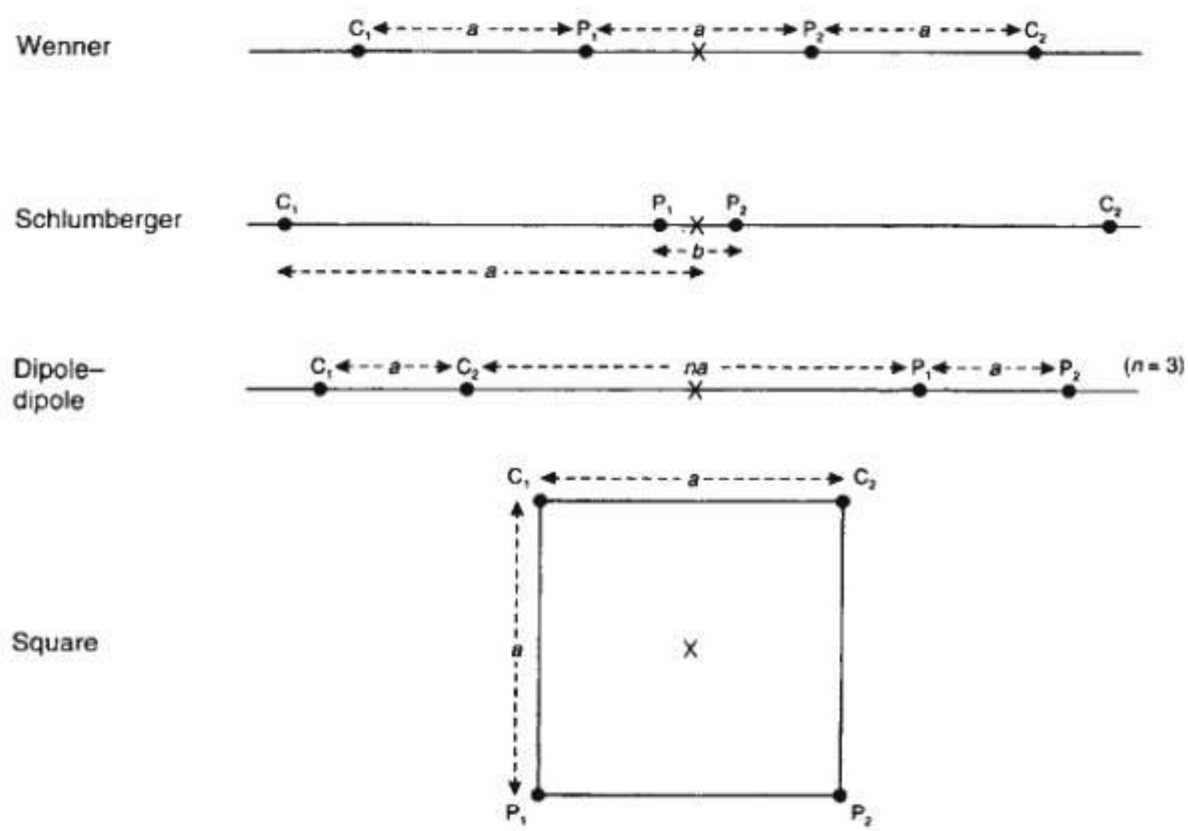

Figure 8: Various configurations for Electrical Resistivity Survey

The apparent resistivity is calculated as,

$$\rho a = K\frac{\Delta V}{I}$$

Here, K is a geometric factor, ΔV— voltage between electrodes M and N, I — current in the line AB. The geometric factor is defined by

$$K = \pi \frac{(C1C2)^2 - (P1P2)^2}{4\,(P1P2)}$$

Here, C1C2 = distance between current electrodes and P1P2 = distance between potential electrodes.

4. DATA PROCESSING, ANALYSIS AND INTERPRETATION

Geo-electrical resistivity survey is widely used geophysical method for groundwater exploration, environmental application and other engineering application. The benefit of this method is to perform the survey quite fast and in the cost-effective manner. Detection of water table, variation of resistivity with depths (distinguishing layered earth), contaminants plume detection, detection of bedrocks depth, overburden thickness, types of subsurface geology etc. are the objectives geo-electrical resistivity survey. The interpretation of electrical resistivity data is the process of deriving the values of true resistivity (ρ) and thicknesses (t) of various subsurface strata from the values of recorded resistance (R) or apparent resistivity (ρ_a) at electrode separations (a). There are a number of interpretation techniques for evaluating (ρ) and (t) of each of the stratum as proposed by many investigators. These can be grouped as analytical, numerical, empirical, graphical, computer (software) based etc. and several amongst each category.

In qualitative interpretation, general conclusive remarks regarding to lithological variation are made in terms of apparent resistivity values. The data acquisition, data filtering and interpretation was carried using standard norms by Geophysicist and Hydro geologist. For VES the apparent resistivity values $\boldsymbol{\rho_a}$ were plotted against the electrode spacing (AB/2) on a log-log scale to obtain the VES sounding curves using the computer software RES1D software which is developed for the purpose of data processing, analysis and interpretation. The field curves together with the best fit model curve of sounding site is drawn in double log-log sheet, lithological section.

The basic principle behind the relation between resistivity data and lithology/geology are already dealt with in above sections.

The general resistivity values of different earth materials are shown in Table 4 &5. The resistivity of certain layer depends up on rock type, grain size, degree of void spaces and amount of water present, degree of weathering, mineral constituents etc. Based on general geology of study area and different studies carried out in different part of Nepal, the general correlation table has been prepared which is shown in table no.6.

Table 6: Correlation of Resistivity and Lithology

Kathmandu (JICA, 1990)		**Chitwan (BWRDB, 1996)**		**Pokhara (P. Gautam et al., 2000)**	
Lithological Description	**Resistivity Range (Ohm-m)**	**Lithological Description**	**Resistivity Range (Ohm-m)**	**Lithological Description**	**Resistivity Range (Ohm-m)**
Clay and silt	<15	Clay	<20	Top Soil	415-1749
Sandy clay	15-50	Silt, Clay	<50	Silt and Clay	13-1793
Clayey Sand	50-100	Silt, Fine Sand	50-100	Conglomerate (Boulder, Cobble, Pebble in sandy matrix)	2131->25000
Sand and gravel	100-500	Fine to Coarse Sand	100-200	Gravel with higher amount of Fine materials and high Moisture Content	495-8728
Basement	>500	Gravel, Coarse Sand	250-1000		
		Boulder, Cobble, Fractured bedrock	+/-2000		

		Boulder, Cobble, (Above water table)	+/-4000		

4.1 Analysis and Interpretation of VES data

The apparent resistivity values are used to prepare contour maps at different intervals of current electrode separation (AB/2) by using ArcGIS software. These maps help to visualize the lateral and vertical lithological variation. These maps reflect the lateral variation of apparent resistivity over a horizontal plane at a certain depth. In other words, these maps indicate distribution of apparent resistivity in the area against distance of current electrodes. The maximum depth penetration of the Schlumberger method is 1/3 to 1/4 of the maximum distance of current electrodes.

Then the apparent resistivity, ρa, values were plotted against the electrode spacing (1/2AB) on a log-log scale to obtain the VES sounding curves using computer software RES 1d. It is designed for automated and interactive semi-automated interpreting of vertical electric sounding. The typical sounding curve for recorded in the study area and interpretation made to obtain estimates of layer properties are illustrated in figure 10 to 12.

Two profiles were selected for the VES resistivity survey, these profiles VES1 and VES2 are intersected to each other in the point of interest for groundwater exploration. This survey helps to correlate the lithological interpretation of two VES point. Different perspective helps to correlate the information of the depth provided by the data. Two points from different axis in same point may help to relate the information of the particular point.

VES Point Description

Location 1: Dipayal Silgadi -03 Doti

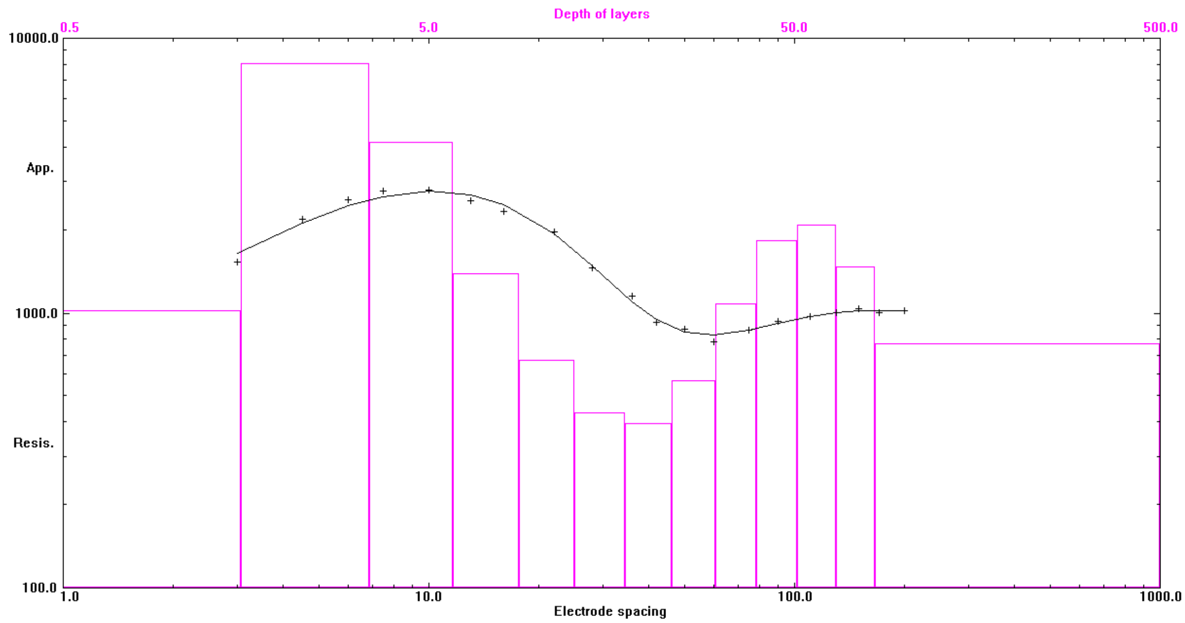

Figure 9: VES curve showing Electrode spacing vs Depth of Layers and Resistivity

Table 7: Table showing thickness, resistivity and Lithology based on VES survey

Layer No.	Thickness (m)	Cumulative Thickness (m)	Resistivity (ohm-m)	Possible Lithology
1	1.5	1.5	1050	Moist colluvial deposit containing cobbles of weathered schists
2	2	3.5	8000	Dry colluvial deposit
3	2.5	6	4500	
4	3	9	1500	Damp colluvial and/or alluvial deposits
5	3.5	12.5	700	
6	5	17.5	450	Slightly wet alluvial deposit of sand and fine gravel in dominant proportion
7	5	22.5	400	
8	7.5	30	600	
9	10	40	1050	Damp fractured rock(regolith)
10	10	50	1800	Dry bed rock
11	14	64	2100	
12	19	83	1600	
13	17	100	800	

Geophysical survey, the VES resistivity exploration along the profile VES1 that revealed six significant layers (table 7). The first layer has thickness of 1.5m composed of moist colluvial deposit, clasts of weathered schist up to cobble size. Following second layer has increased resistivity value of 8000ohm-m indicating the dry colluvial deposit. Third layer has damp colluvial or alluvial deposit which must be damp. The fourth layer starts from 12.5m which is 17.5m thick. It has decreased value of resistivity, must be because of the presence of ground water in minor quantity due to which slightly wet alluvial deposit of sand fine gravel. Below this layer slightly increased value of resistivity (1050ohm-m) suggests regolith that must be damp. The final layer has relatively higher value of resistivity up to 2100ohm-m, which is not suitable value for the possibility of ground water. This must be dry bed rock, probably quartzite or schist.

Location 1: Dipayal Silgadi -03 Doti

VES 2

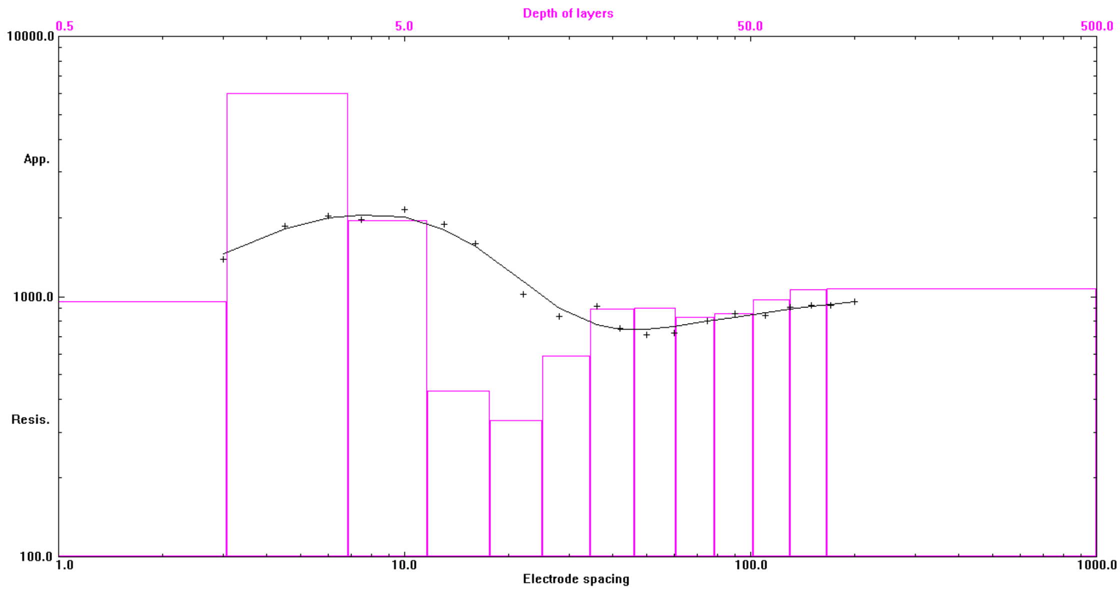

Figure 10: VES curve showing Electrode spacing vs. Depth of Layers and Resistivity

Table 8: Table showing thickness, resistivity and Lithology based on VES survey

Layer No.	Thickness (m)	Cumulative Thickness (m)	Resistivity (ohm-m)	Possible Lithology
1	1.5	1.5	950	Moist colluvial deposit containing cobbles of weathered schists
2	2	3.5	6000	Dry colluvial deposit
3	2.5	6	2000	
4	3	9	450	Slightly wet alluvial deposit of sand and fine gravel in dominant proportion
5	3.5	12.5	350	
6	5	17.5	650	
7	5	22.5	920	Damp alluvial deposits
8	7.5	30	950	
9	9	39	850	Damp fractured rock (regolith)
10	13	52	900	
11	15	67	1050	Dry bed rock,
12	16	83	1100	
13	17	100	1125	

Second profile VES2 at the same location is worked out revealing six significant layers. The first 1.5m depth is composed of moist colluvial deposit with cobbles of weathered schist. Second layer has sharply increased resistivity value that is 6000ohm-m regarding dry colluvial deposits. The third layer has decreased value of the resistivity, the lowest value being 350ohm-m indicating presence of some ground water forming the alluvial deposit to be wet. Following fourth layer has slightly increased value for the resistivity denoting only damp alluvial deposit; below this layer damp regolith must be present. This layer has medium value of resistivity with the value in order of 800-900 ohm-m. Deepest layer detected from the VES survey has thickness of 48m, with slightly higher value of resistivity indicating dry bedrock (table 8).

From the observation through two VES survey data mentioned above, sub surface layers of this location has little probability of ground water at the depth around 20 to 30m. In this range of depth, there is chance to encounter with slightly wet alluvial deposit (fine gravel and sand) as the partially saturated aquifer, but perennial availability doubtful.

Location 2: Dipayal Silgadhi -03

VES 3

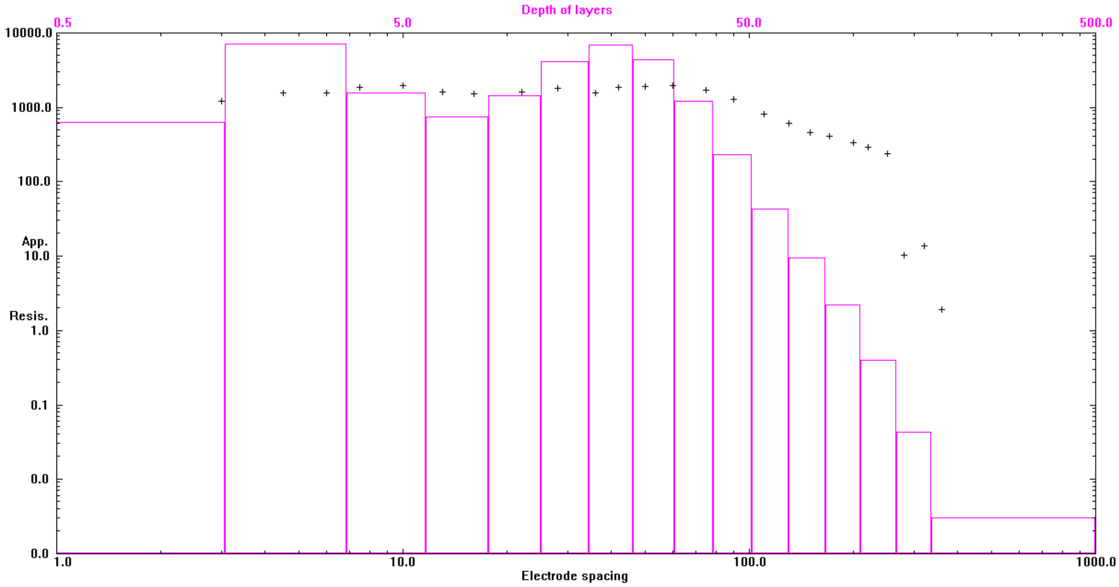

Figure 11 : VES curve showing Electrode spacing vs. Depth of Layers and Resistivity

Table 9: Table showing thickness, resistivity and Lithology based on VES survey

Layer No.	Thickness (m)	Cumulative Thickness (m)	Resistivity (ohm-m)	Possible Lithology
1	1.5	1.5	600	Damp colluvial deposit containing cobbles of weathered quartzite and schist
2	2	3.5	7000	Dry colluvial deposit
3	2.5	6	1500	
4	3	9	700	Damp colluvial and/or alluvial deposits
5	3.5	12.5	1400	Dry colluvial and/or alluvial deposits
6	5	17.5	4000	
7	5	22.5	7000	
8	7.5	30	1450	
9	8	38	1150	
10	14	52	200	Partially wet fractured rock (regolith)
11	15	67	150	
12	16	83	10	Wet fractured rock, goof for the ground water potential
13	22	105	2.1	
14	28	133	0.4	
15	32	165	0.05	
16	10	175	0.03	

The VES survey at this location revealed the subsurface data up to depth 175m, comprised of six significant major layers (table 9). The first layer is of damp colluvial deposit with resistivity value of 600ohm-m not significant for ground water. Following second layer has thickness of 2m, differentiated by sharply increased value of resistivity (7000ohm-m) indicating dry colluvial deposit. Below which the third layer has slightly decreased value of the resistivity suggesting damp colluvial deposit. The fourth sub surface layer has slightly increased, medium range of resistivity value. This layer is interpreted to be of dry colluvial and alluvial deposit or the weathered bed rock of schist. The value of resistivity accidentally drops to 200ohm-m suggesting the encounter with the fifth layer. This layer must be composed of partially wet fractured rock which seems favorable for the ground water storage, but not as equal to the lower sub surface layer. The sixth major layer as detected by the VES survey resembles high potential for the ground water storage due to the greatly decreased value of resistivity value. This location has magnificent chance to acquire ground water at the depth below 80m.

5. DISCUSSION AND CONCLUSION

Hydrogeologically, Lesser Himalayan region, which is characterized by complex geological and tectonic processes, resulting in diverse hydrogeological conditions. The hydrogeological conditions of the Lesser Himalayan region are influenced by a range of factors, including topography, geology, climate, land use, and human activities. Slightly to highly fractured rock may help to increase the permeability and placed the water in an aquifer so that this could be extracted to the people according to the use. According to the VES data, **location VES1 point is contained on the bed rock which shows the high resistivity value does not show the possibility of ground water for the exploration.** While the location second **VES3 may have the potential for the exploration of ground water as the resistivity value indicates the presence of ground water and contained the aquifer zone**. The high resistivity value of the strata might potentially act as. barriers to different aquifer zones. The VES3 point suggests that water bearing lithology consist on the end most part. The high resistivity value indicates the presence of intact rock in the midway of the depth while in the top this high resistivity value obtained due the regolith. The upper portion regolith may be slightly weathered which helps in the infiltrate the water and captured down to the bed rock. The VES point had done near the bank of river contain alluvial deposit which help to infiltrate the water and going down to the depth and preserved on the bed rock and formed an aquifer. The topography of the region is characterized by steep mountain ranges, deep valleys, and narrow river channels, which influence the recharge and discharge of groundwater. The region receives heavy rainfall during the monsoon season, which contributes significantly to groundwater recharge. However, due to the steep topography and high runoff rates, much of the recharge occurs through the river channels, resulting in limited groundwater availability in the upland areas.

The final outcome of the survey suggest that first location is not suitable for the sump well or for the extraction of water while the second location of the VES survey inform that there is the availability of water.

List of Table

List of Figure

6. PHOTOGRAPHS