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Impacts of Terrain Conductivity Survey for Groundwater Investigation in a Typical Sedimentary Formation; A Case Study of Itori, South-West Nigeria

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ABSTRACT
A geophysical investigation for groundwater development involving conductivity measurement using Electromagnetic profiling was conducted to locate fractured and fissured zones and associated groundwater containing media at Itori communities, Southwestern Nigeria. The area is underlain by the typical sedimentary rocks of South-West, Nigeria with the local geology predominantly clay, shale, clay sand, limestone and Sandstone. Measurements of the ground conductivity were carried out with Geonics EM 34-3 along 5 traverses whose profile lengths varied between 160 and 200 m. Intensive geophysical fieldworks were performed utilizing Frequency Domain Electromagnetic Method (FDEM) using Geonics-EM-34 to determine the vertical and lateral variations of subsurface conductivity probing depths of 20 m, 40 m and 60 m. The EM data were acquired at 500 m intervals along 10 profiles. The Vertical Dipole Moment in the first layer exhibited the highest true conductivity and lowest true conductivity of 42.65 *mS/m* and 29.1 *mS/m* for EMITO1 and EMITO2 respectively and the corresponding Horizontal Dipole Moment exhibited the highest true conductivity of 36.0 *mS/m* and 25.41 *mS/m* for EMITO1 alongside EMITO2 and EMITO8 respectively while the Vertical Dipole Moment in the second layer exhibited the highest true conductivity of 45.62 *mS/m* and lowest true conductivity of 34.76 *mS/m* for EMITO1 and EMITO8 respectively and the corresponding Horizontal Dipole Moment exhibited the highest true conductivity of 44.0 *mS/m* and lowest true conductivity of 36.3 *mS/m* for EMITO3 and EMITO8 respectively. The qualitative interpretation of EM results identified areas of hydrogeologic importance and forms a predictive and suggestive basis for Vertical Electrical Sounding (VES) investigation; points of positive EM anomalies were considered as priority area for electrical resistivity sounding and prospective groundwater development, since they suggest lithological variations within the unconsolidated overburden and/or water–filled fissures in the bedrock. The identified major geological interfaces were suspected to be of weathered zones.

Keywords:
Electromagnetic Survey,
Groundwater,
Development,
Sedimentary terrain.

INTRODUCTION

The subtle and inhomogeneities of the subsurface alongside with the abrupt changes in lithology, electrical properties and variable thicknesses of weathered bedrock materials often make the interpretation of EM data from sedimentary terrain difficult. One of the most difficult tasks ever encountered by man has been the pathway to the understanding of the earth; it is based solely on what can be observed how well the observer can perceive and interpret his observation. The study area falls on latitude of 6°56'22.44''N and a longitude of 3°13'14.38''E with elevation of 27.25 meters (89.42 Feet) (Ishola., 2019). The study area lies within the sedimentary terrain of Southwestern Nigeria and transits largely into sediments of the Dahomey basin. The geophysical investigation involving the use of electromagnetic (EM) method was carried out in the study area to investigate the groundwater prospects of the area. Electromagnetic (EM) profiling is a widely used geophysical method in the delineation of overburden formation rocks and clay regolith and location of fissured media and associated zones of deep weathering of the consolidated sedimentary terrains (Beeson, *et al*., 1988., Hazell, *et al.,* 1988, Olayinka, 1990, Olayinka, *et al.,* 2004). In many instances, reconnaissance EM surveys are used for locating aquiferous zones such as fractures, faults and joints.

Geophysical methods play an increasing significant role in the search for these suitable and productive groundwater reservoirs (Ishola *et al.*, 2021). Electrical resistivity method has been used routinely in exploration for groundwater. However, several other geophysical methods have been applied successfully either singly or in combination, for prospecting for groundwater resources in varying geologic situations. The electromagnetic method has found useful applications in groundwater investigation in both Basement and sedimentary terrains, most especially as a reconnaissance tools to understand the nature and groundwater development feasibility of a suspected aquiferous zone (Worthington, 1977. Palacky *et al.,* 1981; De Jong *et al.,* 1981; Amadi and Nurudeen, 1990; Olorunfemi *et al.,* 2001; Egwebe *et al.,* 2004; Ariyo *et al.,* 2009; Okafor and Mamah, 2012; Ishola., 2019; Ishola *et al*., 2021). The main advantage of the EM- methods is that they do not require direct contact with the ground as in the case of Direct Electrical methods. Therefore, the EM- measurement can be carried out in a faster way than the DC measurement making it a very useful method for rapid assessment together with other more accurate methods. EM does not accept any individual reading if it is significantly different from adjacent readings and build a subsurface picture based on all the readings along the survey line and adjacent lines (Ishola, 2019). Also, Electromagnetic method can be applied singly or alongside with other geophysical techniques such as gravity, seismic refraction, and electrical resistivity methods during the search for groundwater depending on whether the search is on a regional or local scale. This study is focused on assessing the groundwater prospect of the study area, and more importantly, providing information on the hydrogeologic framework of major aquifer units, and delineation of areas suitable for drilling and installation water wells.

MATERIALS AND METHODS

Study Area

Itori is located on a latitude of 6°56'22.44"N and a longitude of 3°13'14.38"E with an elevation of 27.25 Meters (89.42 Feet). Historically, the people of Itoriland, like other settlers in Ewekoro Local Government Area of Ogun State, migrated from Egbaland. Today, Itori has over thirty thousand population with a highly organized communal system and well behaved youths unlike past few years when the population was less than five hundred and serves as the headquarter of the entire Ewekoro Local Government Area of Ogun State (Ishola, 2019).

Local Geology of the Study Area

The Ewekoro formation is the local geology in the study area which is generally consistent with the regional geology of the eastern part of the Dahomey Basin; predominantly comprises the non-crystalline and highly non-fossiliferous and fossiliferous limestone and thinly laminated fissile and probably non-fossiliferous shale (Ushie *et al.*, 2014; WAPC, 2000). It is the sedimentary terrain of southwestern Nigeria. Ewekoro formation consists of intercalations of argillaceous sediment. The rock is generally soft and friable but in some places, it is often plastered by materials that are siliceous and ferrigeneous types. The three informal formational units of Abeokuta group are Ise, Afowo and Araromi formations. The strata previously referred to as the Nkporo shale were renamed Araromi formation by Okosun (1998). The Abeokuta formation on surface outcrops comprises mainly sand with sandstone, siltstone, silt, clay, mudstone and shale interbeds. It usually has a basal conglomerate which may measure about 1m in thickness and usually consists of poorly rounded quartz pebbles with silicified and ferruginized sandstone matrix or a softly gritty white clay matrix. In outcrops where there is no conglomerate, a coarse, poorly sorted pebbly sandstone with abundant white clay constitutes the basal bed. The overlying sands are coarse grained clayey, micaceous and poorly sorted and indicative of short distances of transportation or short duration of weathering and possible derivation from the granitic rocks located to the north while the subsurface data of the Abeokuta formation were provided by Ise-2, Afowo-1, Orimedu-1, Bodashe, Ileppawi, Ojo-1 and Itori boreholes (Okosun, 1998; Oladeji, 1992). The formation thickness values of 849 m, 898 m, 624 m, 54.4 m and 888 m were respectively acquired for Ise-2, Afowo-1, Ileppawi, Itori and Ojo-1 boreholes. Notably in the Ise-2 borehole, the formation is essentially constituents of arenaceous sequence between 1261.5 m and 2142.1 m which in turn consists of sands, grits, sandstone, siltstone, clay and shaly materials. Very coarse loose sands with sporadic thin intercalations of multicoloured shale and limestone were found within the interval of 1076 m to 1907 m that represent the formation in Ojo–1 borehole. The upper portion of the formation strata from 44 m to 98.4 m in the Itori borehole consists of coarse-fine and medium-grained sand, silt and sandy clay horizons. Basal conglomerates are also penetrated Ise-2 borehole (Ishola *et al*., 2019). The inset map showing political divisions of the study area within the Nigerian continental environment is shown in Figure.1 while Figure. 2 shows the Geological Map of the Selected Locations of the Study Area within the Nigerian Part of Dahomey Embayment, and the maps of the investigated locations in the study area are shown in Fig. 3.

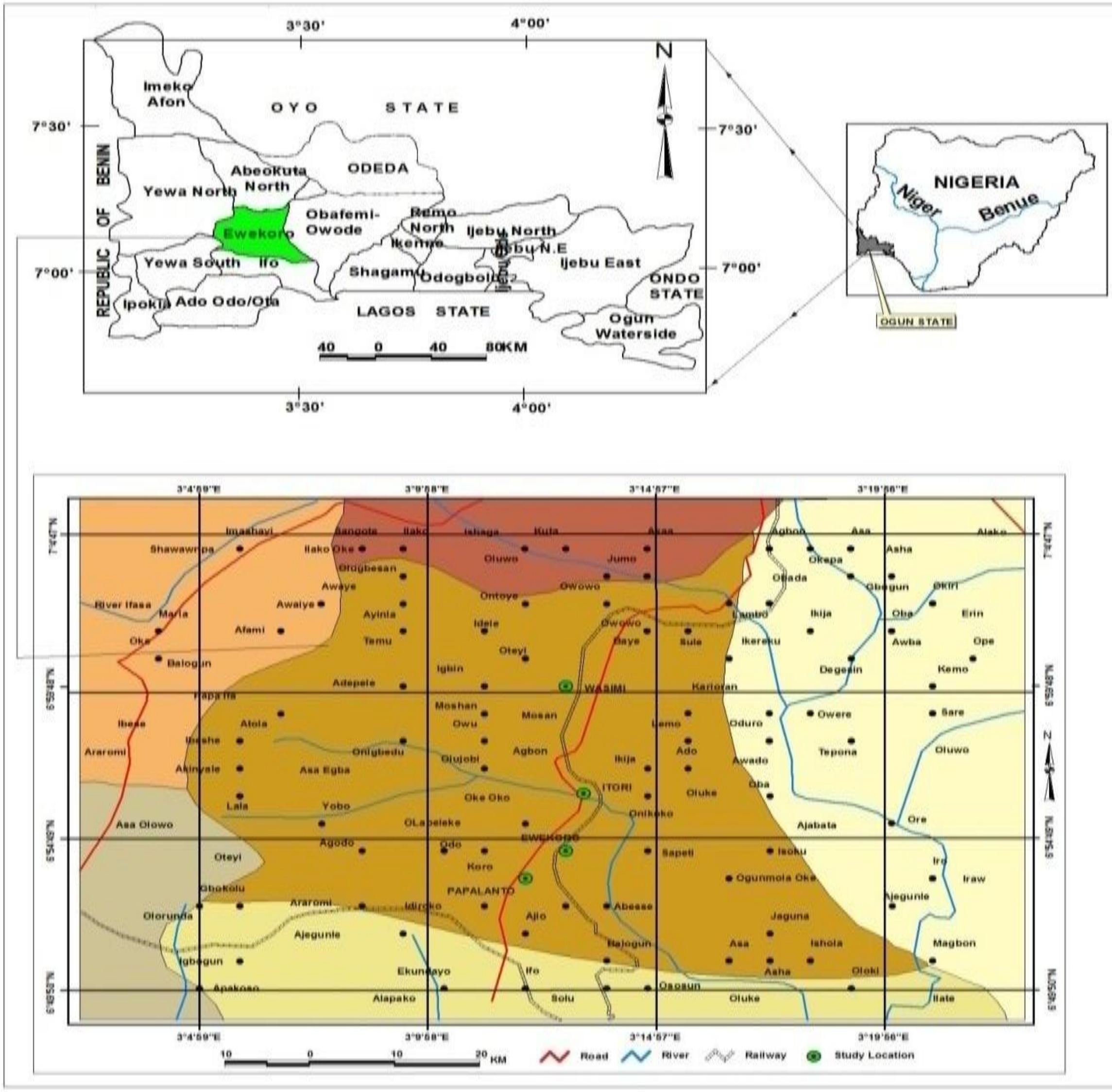


Figure 1: Inset Map showing the Study Areas in Ogun State within Nigeria Continental Domain (Arcview GIS 3.2A Environment, Ishola., 2019)

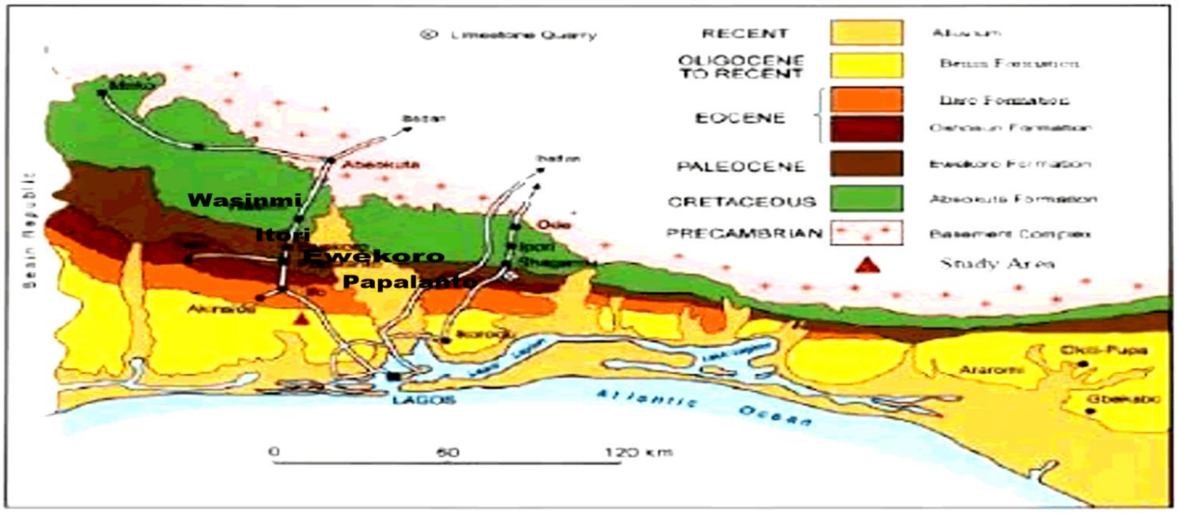


Figure 2: Geological Map Showing the Selected Locations of the Study Area within the Nigerian Part of Dahomey Embayment (Billman, 1992; Modified by Ishola, 2019)

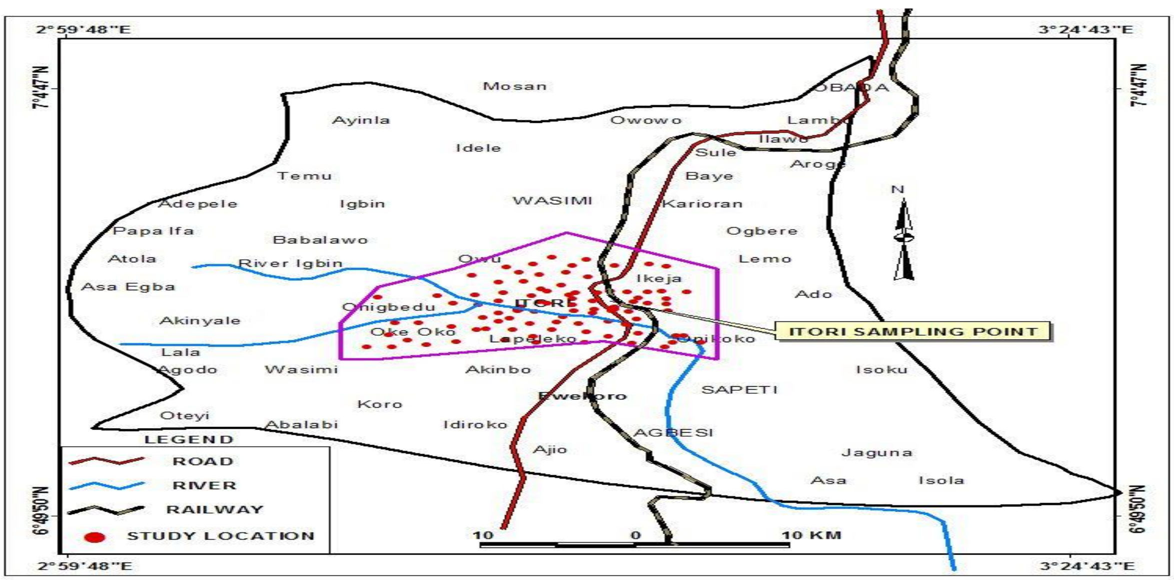


Figure 3: Data Acquisition Map showing the Investigated Locations in Itori Study Area in Ewekoro LGA, Southwest Nigeria (Ishola, 2019).

Theoretical Background

Electromagnetic method makes use of a response of the ground to the propagation of electromagnetic fields which are composed of an alternating electric intensity and magnetizing force. Electromagnetic method does not require contact with the ground, therefore the speed with which EM can be made is much greater than the electrical method. An electromagnetic field can be generated by passing an alternating current through either a small coil comprising many turns of wire or a large loop of wire.

An electromagnetic field may be defined in terms of four vector functions E, D, H and B, where:

E is the electrical field in V/m;D is the dielectric displac ement in Coulomb/m²;H is the magnetic field intensity i n A/m and B is the magnetic induction in Tesla (Ishola, 2019).

Maxwell's equations using Faraday's law

Experimental evidence shows that all electromagnetic phenomena obey the following four Maxwell equations.

$$\nabla E = -\frac{\partial B}{\partial t} \qquad \text{(McNeil, 1980b; Ishola, 2019)} \qquad (1)$$

Faraday's law shows us how a time varying magnetic field produces an electrical voltage.

Maxwell's equations using Ampere's law

Ampere's law shows us how an electric current and/or a time varying electric field generate a magnetic field.

$$\nabla \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$ (McNeil, 1980b; Ishola, 2019) (2)

Maxwell's Equations infer that lines of magnetic induction are continuous and there are no single magnetic poles.

div B = 0 (McNeil, 1980b; Keary *et al.*, 2002) (3)

It infers that electrical fields can begin and end on electrical charges.

div D = q (McNeil, 1980b; Keary *et al.*, 2002) (4)

Subsidiary equations and wave equation

By using the following subsidiary equations,

$\mathbf{D} = \boldsymbol{\epsilon}\mathbf{E}$, $\mathbf{B} = \boldsymbol{\mu}\mathbf{H}$, $\mathbf{J} = \boldsymbol{\sigma}\mathbf{E}$ (McNeil, 1980b; Keary *et al.*, 2002) (5)

Where J = electrical current density in A/m² ; q = electric charge in Coulomb/m³;ϵ = electrical permittivitiy; μ = magnetic permeability; σ = electrical conductivity (McNeil, 1980b; Ishola, 2019).

From these four Maxwell equations the electromagnetic wave equation can be derived.

Primary and Secondary Fields

Where the subsurface is homogeneous there is no difference between the fields propagated above the surface and through the ground (only slight reduction in amplitude). If a conductive anomaly is present, the magnetic component of the incident EM wave induces alternating currents (Eddy currents) within the conductor (Figure. 5). the eddy currents generate their own secondary EM-field which travels to the receiver. The receiver also detects the primary field which travels through the air. The receiver responds then to the resultant of the arriving primary and secondary fields. Consequently, the measured response will differ in both phase and amplitude relative to the unmodulated primary field (McNeil, 1980b; Ishola, 2019). These differences between the transmitted and received electromagnetic fields reveal the presence of the conductor and provide information on its geometry and electrical properties. The depth of penetration of an electromagnetic field depends upon the frequency and electrical conductivity of the medium through which it is propagating. Electromagnetic fields are attenuated during their passage through the ground (McNeil, 1980b; GEONICS, 1990; Ishola, 2019; Ishola *et al.*, 2021) The amplitude of EM exponentially with dept. The amplitude of EM-radiation as a function of depth relative to its original amplitude A_0 is given by

$A_d = A_0 e^{-1}$ (GEONICS, 1990; Ishola, 2019) (6)

The depth of penetration d can be defined as the depth at which the amplitude of the field A_d is decreased by the factor e^{-1} compared with its surface amplitude A_0. Penetration depth d is given by

$d = \frac{503.8}{\sqrt{\sigma f}}$ (McNeil, 1980b; GEONICS, 1990; Ishola, 2019) (7)

where d is in metres, the conductivity s of the ground is in Sm^{-1} and the frequency of the field is in Hz.

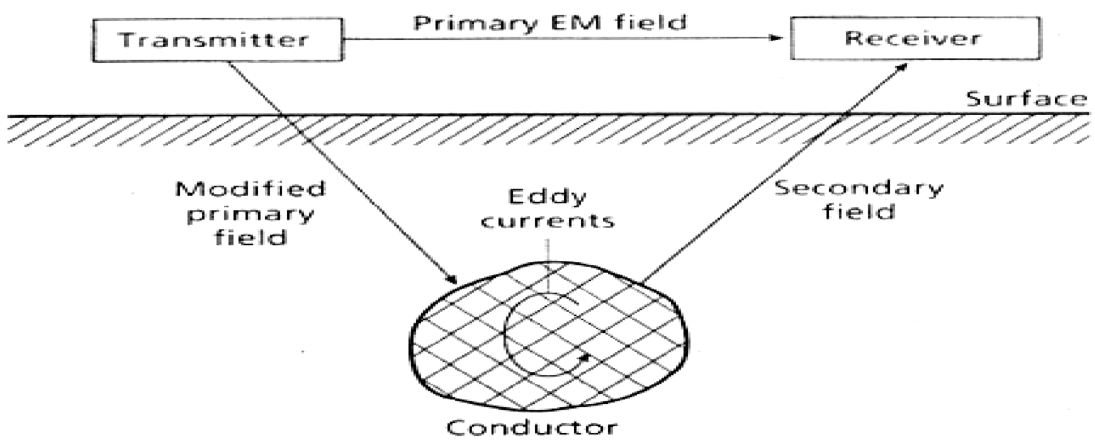


Figure 4: General Principle of Electromagnetic Surveying (Vogelsang, 1995)

The depth of penetration thus increases as both the frequency of the electromagnetic field and the conductivity of the ground decrease. Consequently, the frequency used in an EM survey can be tuned to a desired depth range in any particular medium where equation (7) represents a theoretical relationship. Empirically, an effective depth of penetration z_e can be defined as the depth which represents the maximum depth at which a conductor may lie and still produce a recognizable electromagnetic anomaly.

$z_e = \frac{100}{\sqrt{\sigma f}}$ (GEONICS, 1990; Ishola, 2019). (8)

The relationship is approximate as the penetration depends upon such factors as the nature and magnitude of the effects of near-surface variations in conductivity, the geometry of the subsurface conductor and instrumental noise. The frequency dependence of the depth of penetration places constraints on the EM method. Normally, very low frequencies are difficult to generate and measure and the maximum achievable penetration is usually of the order of 500m (McNeil, 1980b; Keary *et al.*, 2002; Omosuyi et al., 2007; Ishola, 2019). Examples of different Depths of penetration and corresponding frequencies for 10m spacing are f = 10 Hz, d =503 m; f =100 Hz, d = 159 m and f = 1000 Hz, d = 50.3 m.

EM 34-3 Basis, Principle of Operation and Interpretation Technique

The Electromagnetic Ground Conductivity Survey Method used is based on a well established surface geophysical method. The instrument used was the EM 34-3 terrain conductivity meter by Geonics Ltd obtained from the Department of Geosciences, University of Lagos. A change in conductivity of 5 mS/cm was assumed to be measurable with the instrument which provides a direct reading of the apparent conductivity (σ_a) of the ground in units of millimhos per metre (SI equivalent units are millisiemens per metre (mS/m)). The ratio of the intercoil spacing (s) divided by the skin depth (δ) is known as the induction number (Ishola, 2019; Ishola *et al*., 2021).

In FDEM method, HD/VD surveys were carried out using a GEONICS EM-34 meter has separate coils connected by a reference cable provide the basis of the system, which can be 10m, 20m and 40 m long. The effective depth investigations are 7.5 m (HD) and 15 m (VD) for a frequency of 6.4 KHz and separation of 10 m. For a separation of 20 m and frequency of 1.6 Hz, is obtained a depth investigation of 15 m (HD) and 30 m (VD), as soon as, for the separation of 40 m and frequency of 0.4 Hz, the investigation (GEONICS, 1990; Ishola *et al.*, 2021).

Ground Conductivity (Measurements at Low Induction Number)

The instrument (manufactured by Geonics Ltd.) provides a direct reading of the quadrature as the apparent conductivity in mS/m. Consequently, the secondary magnetic field is a complicated function of the inter-coil spacing, (s), the operating frequency (f), and the ground conductivity (σ). However, However, under certain constraints technically defined as "operation at low values of induction number" the secondary magnetic field is a very simple function of these variables incorporated in the design of the EM 34-3 (McNeill, 1980b; Ishola, 2019). It can be shown that if the product of s and the skin depth d, known as the induction number, is much less than unity. Therefore, the ratio of the intercoil spacing (s) divided by the skin depth is known as the induction number B where the induction number is less than one, then the ratio of the secondary to the primary of magnetic fields at the receiver is directly proportional to apparent conductivity.

The ratio of the secondary (H_s) to primary (H_p) magnetic fields at the receiver at low induction n umbers (B<<1) is given by

$$\frac{H_s}{H_p} = \frac{i\omega\mu_B\sigma S^2}{4} \quad \text{(McNeill, 1980b; Ishola, 2019).} \quad (9)$$

The apparent conductivity indicated by the instrument is deduced from equation (9) as:

$$\sigma = \frac{4}{\omega\mu_B S^2}\left(\frac{H_s}{H_p}\right) \quad \text{(McNeill, 1980b; Ishola, 2019).} \quad (10)$$

where:

H_s= amplitude of the secondary electromagnetic field at the receiver coil; H_p = amplitude of the primary electromagnetic field at the receiver coil; ω = angular frequency (ω = $2\pi f$); f = frequency (Hertz); μ_B = the magnetic permeability of vaccum or free space (1.2566×10^{-6} m kg C^{-2}); σ = ground conductivity (mho/m); s = inter coil spacing (m) and $i = \sqrt{(-1)}$, its presence indicating that the quadrature component is measured (McNeill, 1980b; Ishola, 2019).

Thus the ratio of H_s/H_p is proportional to the ground conductivity σ. Since depth d depends on the product of estimation of the maximum probable value of σ allows the selection of f such that the above condition of low induction number is satisfied. The depth of penetration depends upon σ and is independent of the conductivity distribution of the subsurface (Okafor and Mamah, 2012). Measurements taken at low induction number thus provide an apparent σ_a given by

$$\sigma_a = \frac{1}{\rho_a} = \left(\frac{4}{\omega\mu_0 S^2}\right)\left(\frac{H_s}{H_p}\right)_q \quad \text{(McNeill, 1980b; Ishola, 2019).} \quad (11)$$

This relationship allows the construction of elecromagnetic instruments which provide a direct reading of ground conductivity down to predetermined depth.

The measuring system is designed to ensure that with the selected frequency f, for a given inter-coil separation (s), a designed response of H_p for a given transmitter, the only unknown H_s which is measured by the instrument where the subscript q denotes the quadrature phase (Ishola, 2019).

To measure the terrain conductivity the search coil is either held horizontally (measurement in vertical dipole mode) or vertically (measurement in horizontal dipole mode). The results are generally shown in the form of profiles as inductive electromagnetic survey methods are, nowadays, widely used to map near-surface geology by mapping variations in the electrical conductivity of the ground. Such variations generally are caused by changes in soil structure, porosity, clay content, resistivity of the soil water, and degree of water-saturation in the soil (GEONICS, 1990; Ishola, 2019).

Data Acquisition (Electomagnetic Ground Conductivity Survey)

Electromagnetic profiles (using the Geonics EM34-3 equipment) were selectively carried out in autonomous communities in Itori to outline shallow conductive hydrogeological structures probably connected with local water circulation (Okafor and Mamah, 2012).. The results of such a study are also important in the future delimitation of a protected zone from contamination (Ishola *et al.,* 2021). In fact, zones around the natural spas are used for industrial operations, agricultural activities and domestic usage. It is well known that pollutants generated from these activities are mainly transported through surface water. It is then very important to protect the aquifer from those waters. The most efficient and economical way to do that is to make use of the natural overburden (when present) in order to reduce or eliminate the transport of pollutes through the aquifer. Therefore, characteristics of the overburden are important and were one of the goals of the work presented in this study. The data was acquired along 5 North-South profiles with 2 electromagnetic measurements along a traverse with 5 traverses whose lengths varied between 160 m and 200 m to show conductivity changes with distance and depth in each location with an intercoil spacing of 10m, 20m, and 40 m. The distance between measurement points was 500 m. At each site two measurements were made using both, horizontal and vertical dipole mode. The main conductivity contrasts, roughly can now be interpreted as the shallow expression of fractures affecting the sedimentary filling of the hydrogeological structure (Macdonald *et al*., 2005; Ishola *et al.*, 2005).

Data Processing and Interpretation

The data was qualitatively checked by observing if negative apparent conductivity was recorded. Field note was used as a guide to identify if some anomalously high apparent conductivity values due to artifacts are present. EM-34 transverses were restricted to areas far away from the overhead and underground utility cables and buried iron pipelines (Macdonald *et al*., 2005; Okafor and Mamah, 2012).

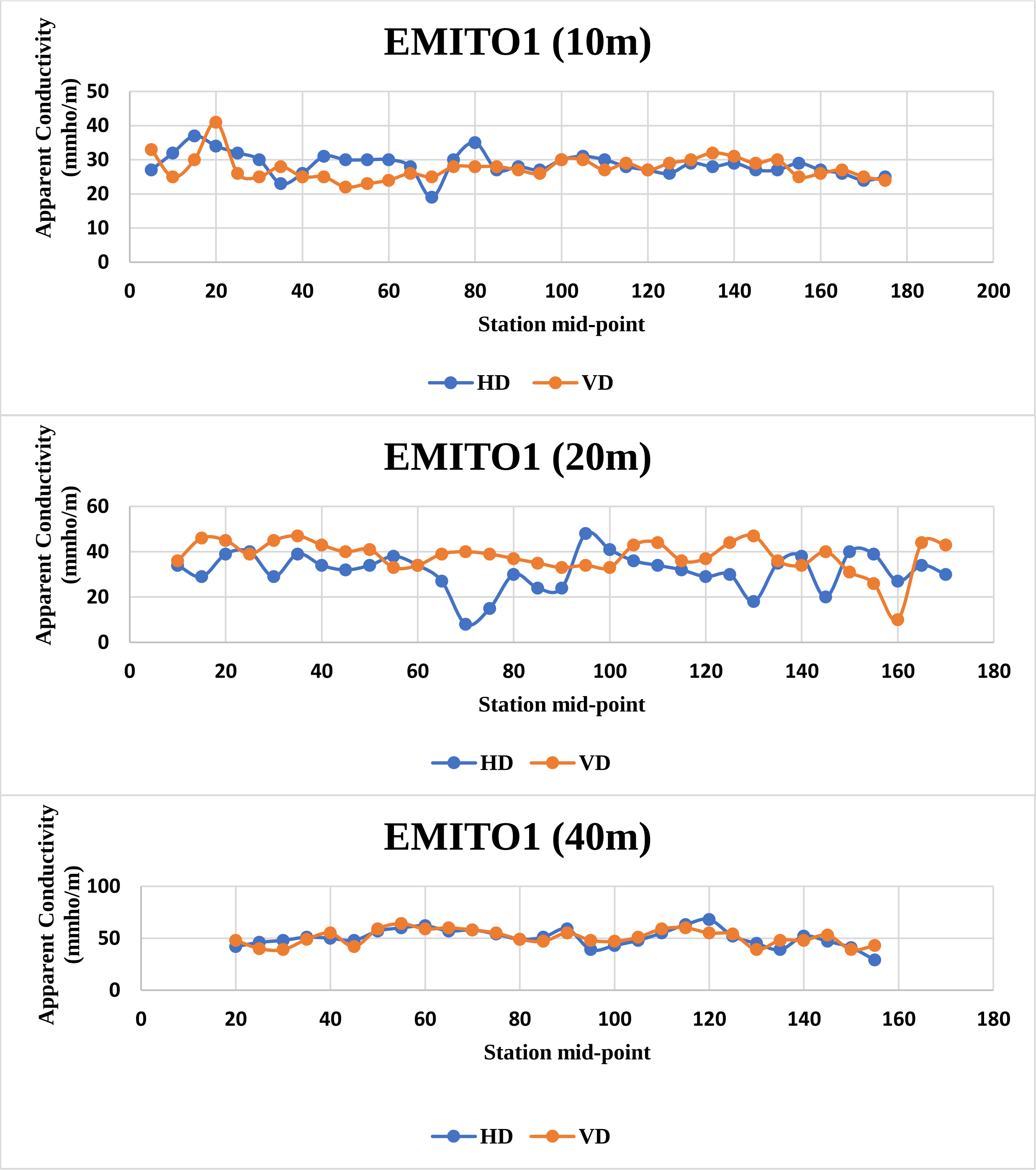
The apparent conductivity reading of the horizontal dipole orientation on each traverse was plotted against station midpoint. This was also carried out separately for the vertical dipole orientation. The crossplots of apparent conductivity on the different spacing enabled a view of how the conductivity varies with depth. Qualitative analysis and interpretation was carried out on the plotted data.

RESULTS AND DISCUSSION

Electromagnetic Profiling Survey Results of Itori

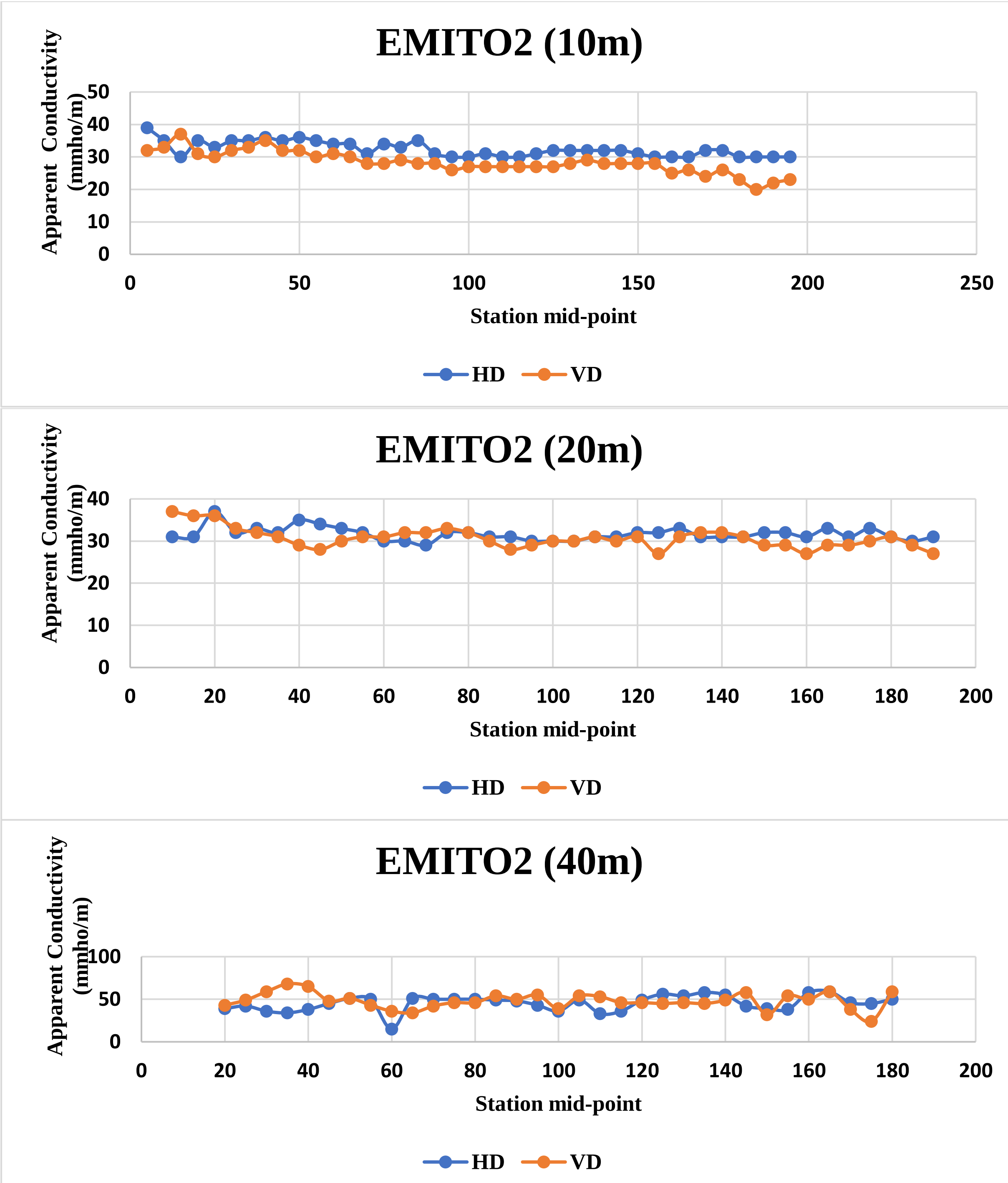
In Itori study locations, five traverses were created with the station intervals of 500 m. The length of each traverse ranged from 150 m to 200 m. Three traverses were established in the West and the East trending the North-South direction and two traverses to the North and the South in the NW-SE direction. On each traverse, the first Profile was created in the W-E direction and second Profile created in the N-S direction with both Profiles having a Profile length of 200 m.

Figure 5.1 to Figure. 6.0 shows the Apparent Conductivity Profiles (EMITO1 to EMITO10) along the traverses conducted at 10 m, 20 m and 40 m seeking different investigation depths. The traverse displays appreciable variation in conductivity and areas of few observable peaks and broad conductivity anomalies were delineated as shown in the plots which could be as a result of fair weathering in the structural disposition of the geological formation of the study area. These locations could be inferred as zones of interest in groundwater exploitations described as slightly weathered/ fractured zone which may serve as a suitable local aquifer (MacDonald *et al.,* 2005). Suggestively, Vertical Electric Soundings can be conducted in locations of broad positive anomalies to investigate and ascertain the target zones of appreciable low resistivity suspected of a typical water bearing or fractured layer (Macdonald *et al*., 2005; Ugwu and Nwosu, 2009) and to confirm the effects of presumed appreciable weathering with depth soundings. The calculated true conductivity values for both horizontal and vertical dipole orientations for the first and second layers and their corresponding depth values in all the profiles were consequently recorded. The highest true conductivity value of 45.62 mS/m was recorded by Vertical Dipole in the 2nd layer for EMITO1 while the lowest true conductivity value of 25.41 mS/m was recorded by Horizontal Dipole in the 1st layer for EMITO10 (Figure. 5.1 and Figure. 6.0). Also the locations with higher conductivity and less variation exemplified in EMITO1 and EMITO2 is suggestive that the subsurface might have been invaded by the contaminant plume; this presumed contaminant plume invasion could be attributed to leachate emanating from the contaminant seepages of the decaying materials at the surface. The relatively higher conductivity representation (25 mmho/m to 68 mmho/m) within the lateral distance of about 100 m to 150 m on both the horizontal and vertical dipole orientations indicate that the subsurface region might have been polluted (Figure. 5.1 and Figure. 6.0).



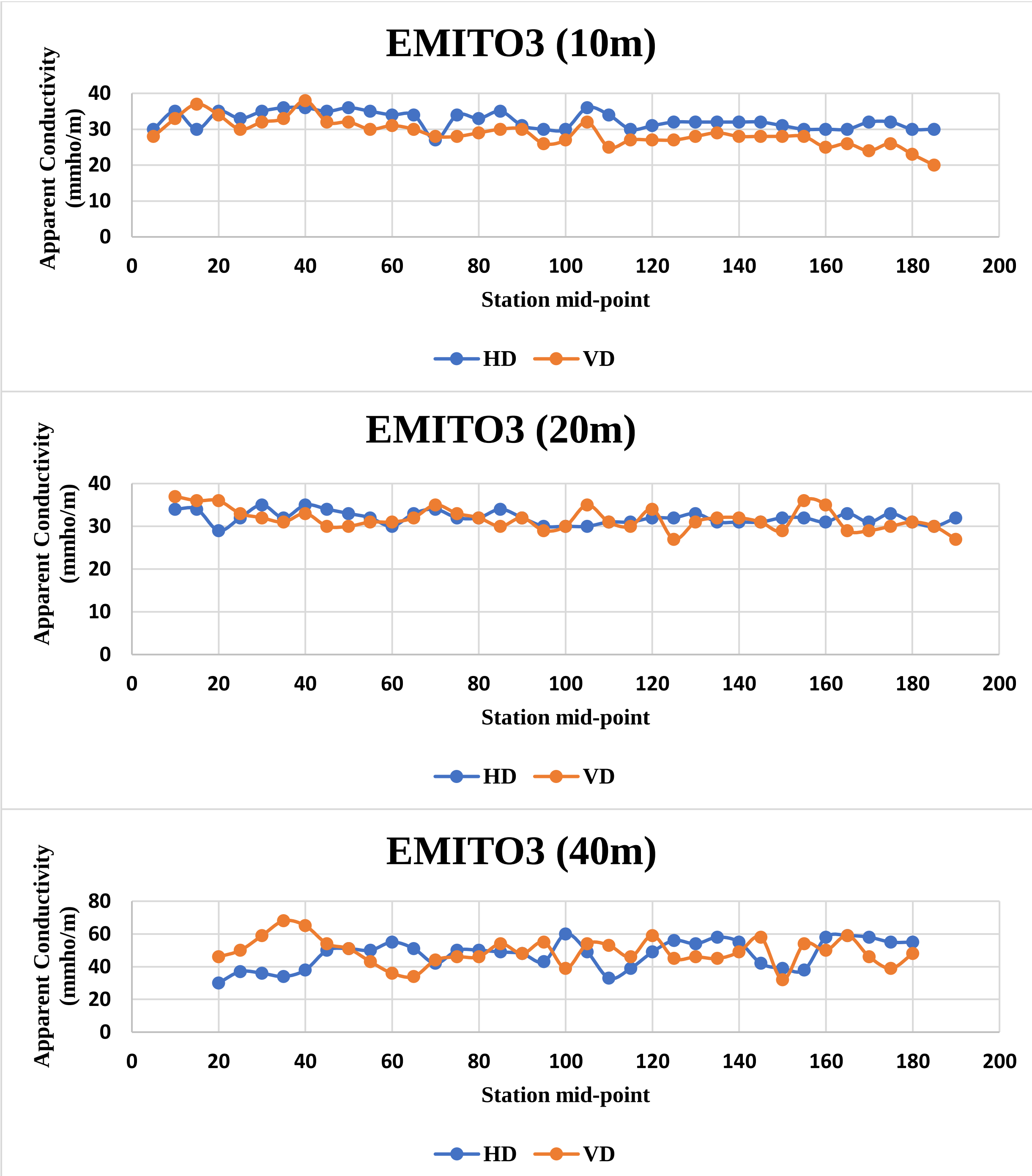
	True Conductivity (mS/m)		Depth(m)	
	HD	**VD**	**HD**	**VD**
1st Layer	36	42.65	2	10.7
2nd Layer	37.2	45.62	-	-

Figure 5.1: Plot and Values of Apparent and Real Conductivity of Horizontal Dipole Orientations along Itori Traverse 1 (Profile 1)



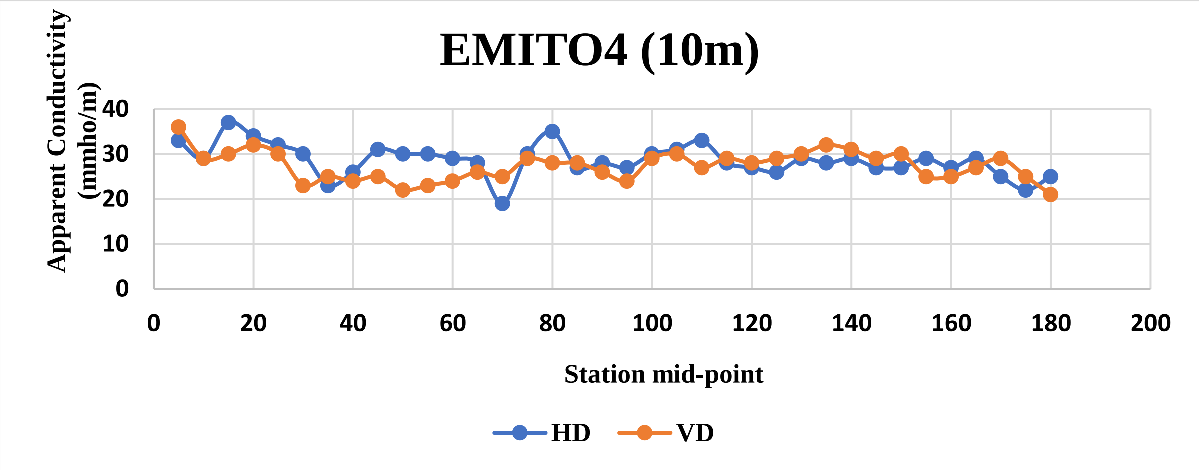
	True Conductivity (mS/m)		Depth(m)	
	HD	**VD**	**HD**	**VD**
1st Layer	35.67	33.57	7.8	18
2nd Layer	38.05	43.29	-	-

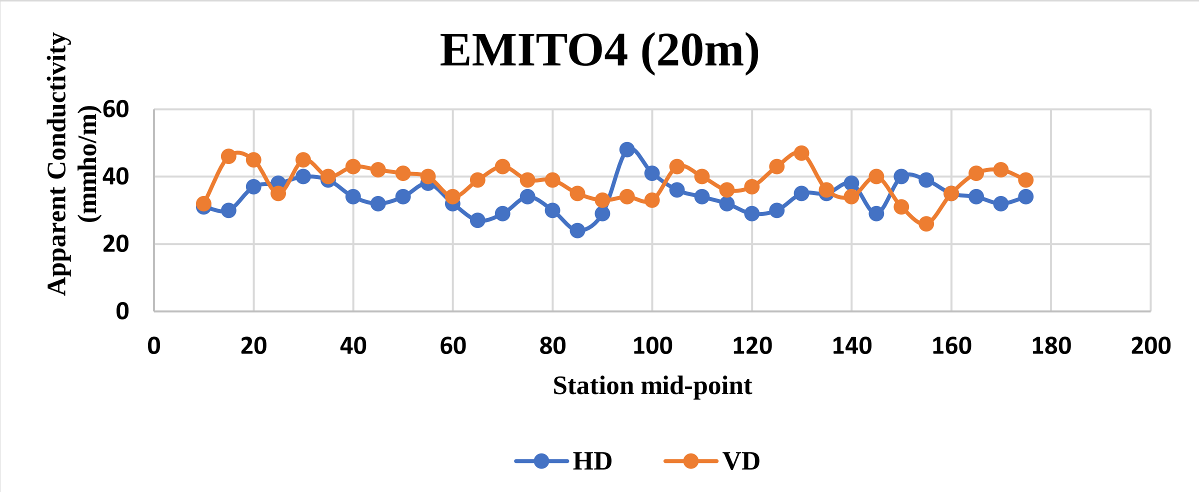
Figure 5.2: Plot and Values of Apparent and Real Conductivity of Horizontal Dipole Orientations along Itori Traverse 1 (Profile 2)

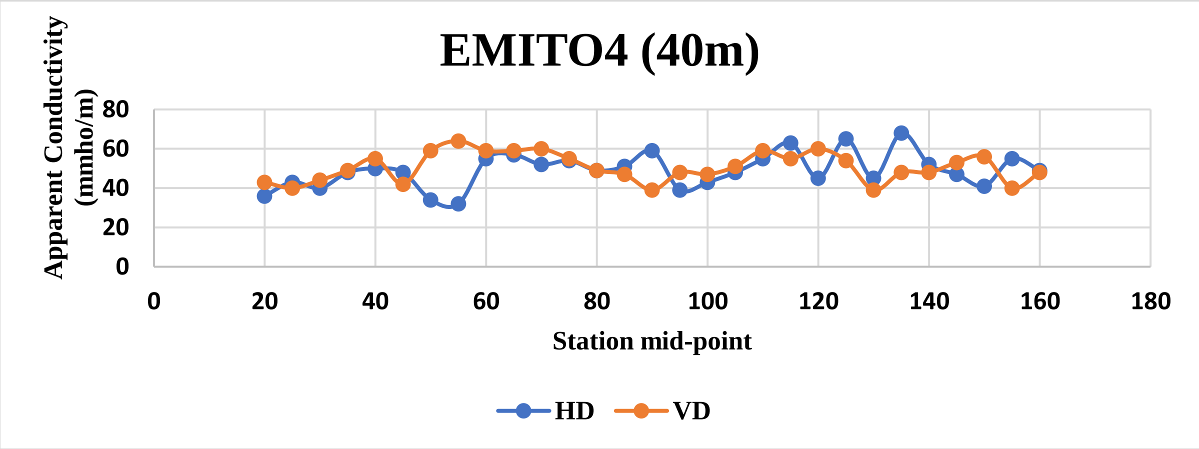


	True Conductivity (mS/m)		Depth(m)	
	HD	**VD**	**HD**	**VD**
1st Layer	29.71	33.24	10.5	19
2nd Layer	44	44.22	-	-

Figure 5.3: Plot and Values of Apparent and Real Conductivity of Horizontal Dipole Orientations along Itori Traverse 2 (Profile 3)

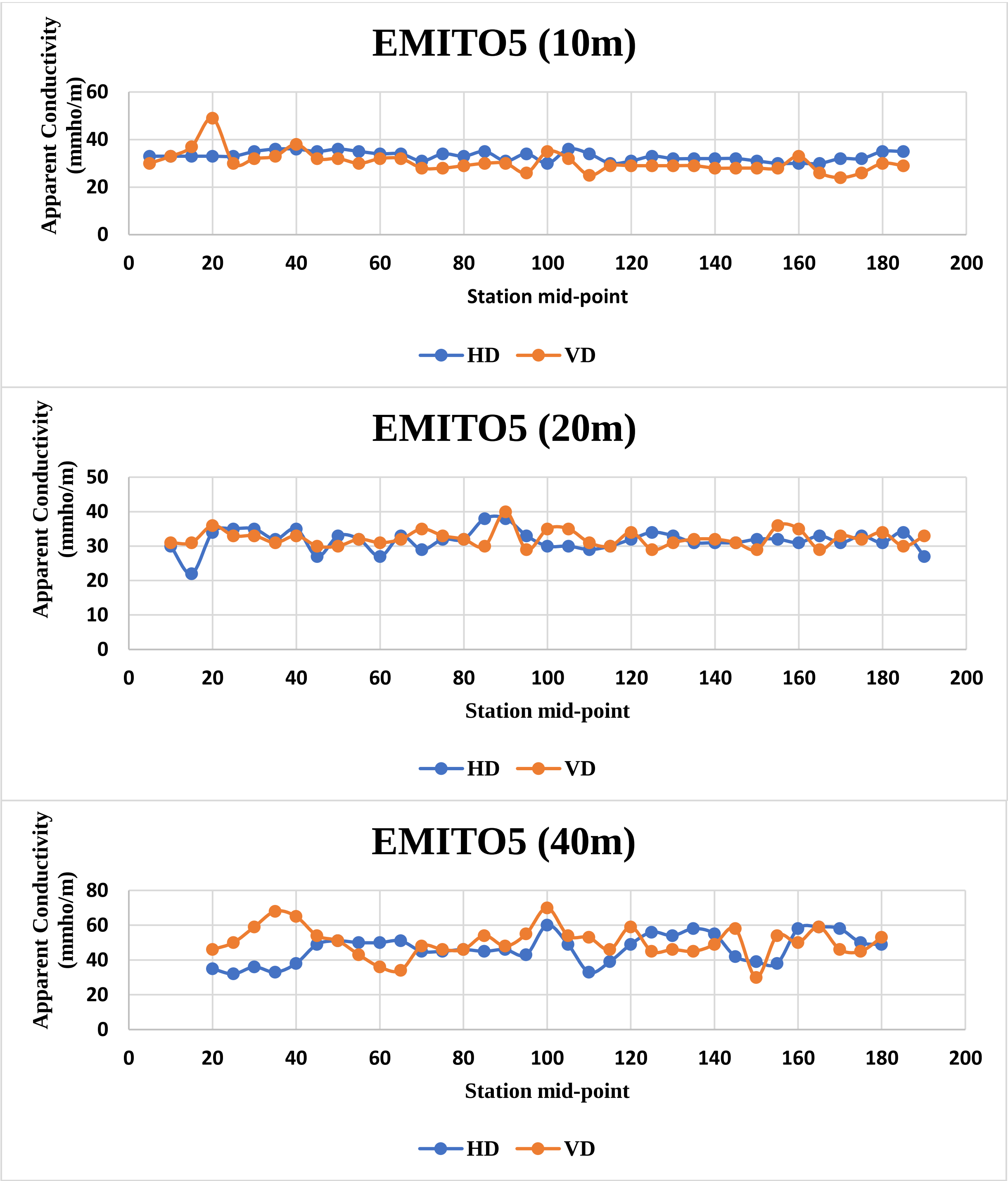






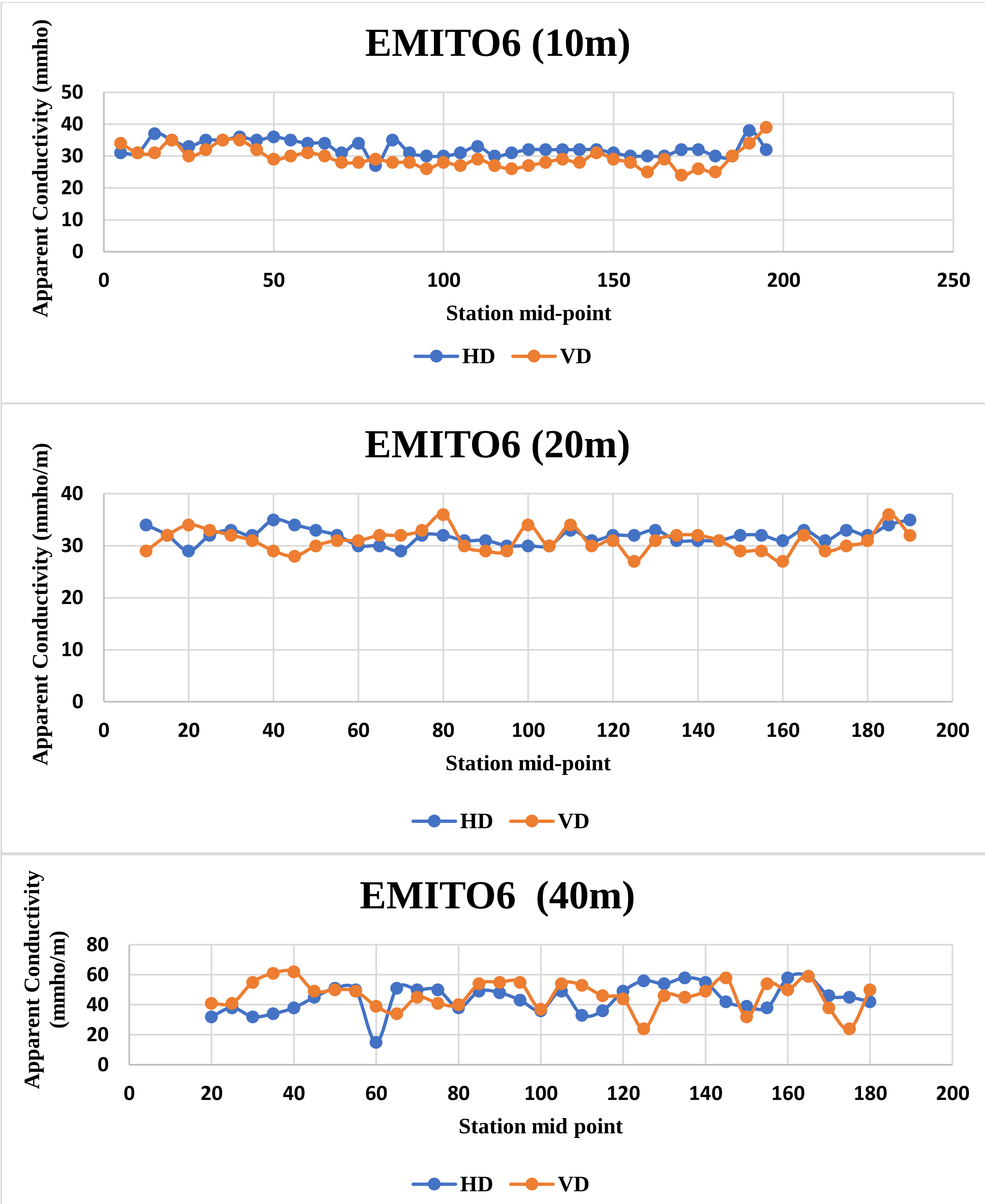
	True Conductivity (mS/m)		Depth(m)	
	HD	**VD**	**HD**	**VD**
1st Layer	33.88	32.36	5.6	14.5
2nd Layer	39.09	38.24	-	-

Figure 5.4: Plot and Values of Apparent and Real Conductivity of Horizontal Dipole Orientations along Itori Traverse 2 (Profile 4)



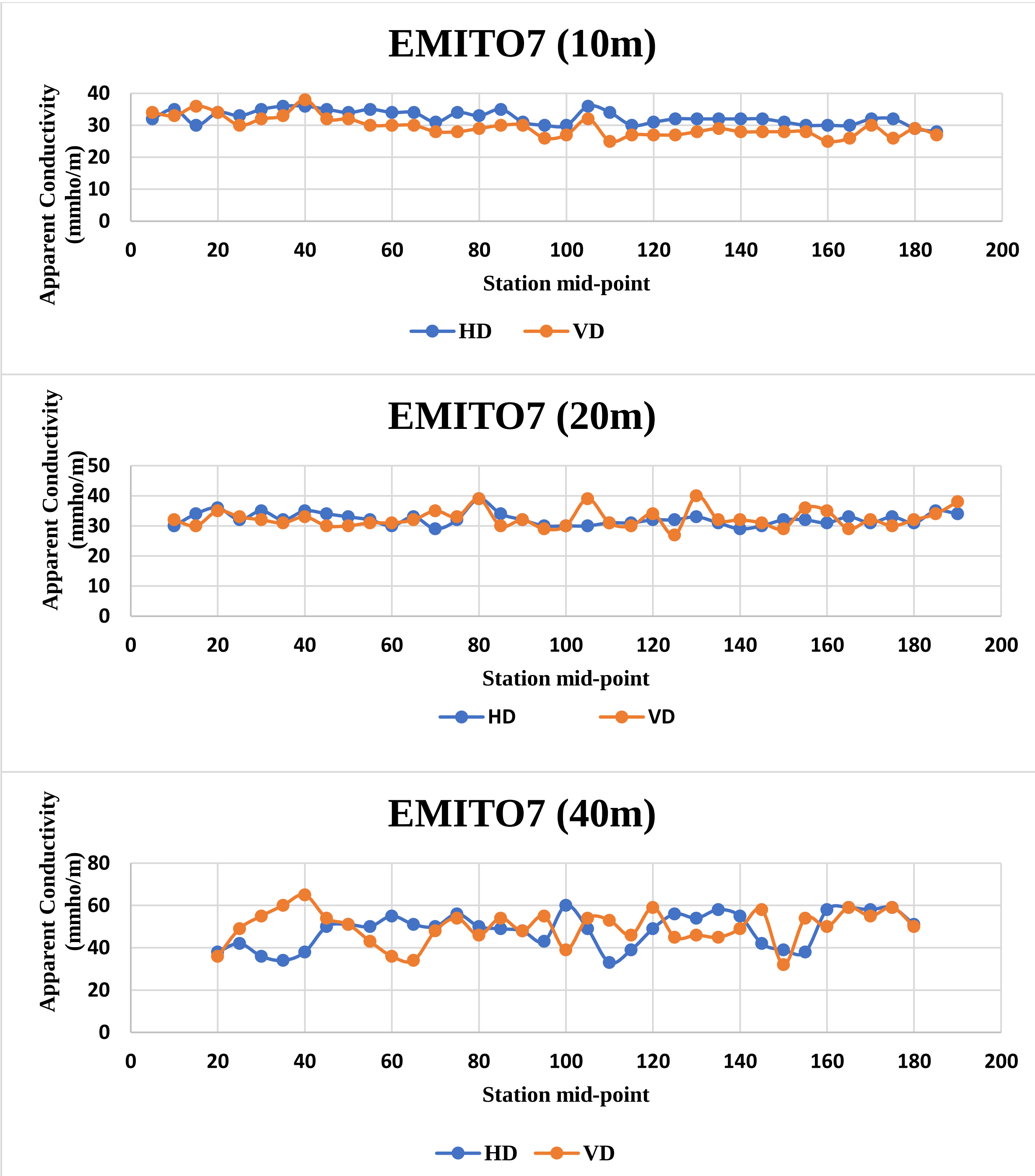
	True Conductivity (mS/m)		Depth(m)	
	HD	**VD**	**HD**	**VD**
1st Layer	34.34	36.56	8.9	11
2nd Layer	42.67	40.96	-	-

Figure 5.5: Plot and Values of Apparent and Real Conductivity of Horizontal Dipole Orientations along Itori Traverse 3 (Profile 5)



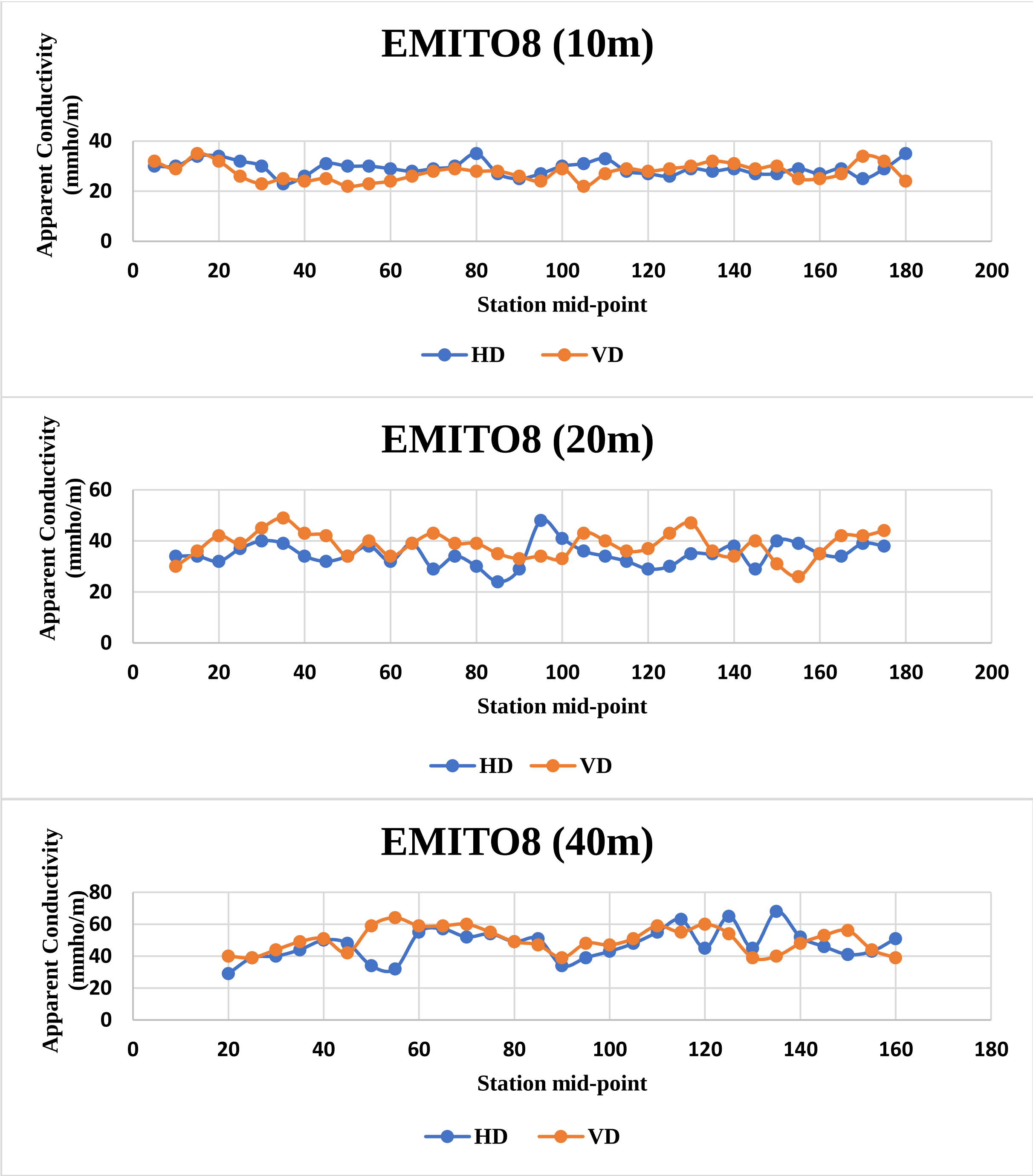
	True Conductivity (mS/m)		Depth(m)	
	HD	**VD**	**HD**	**VD**
1st Layer	28	32.3	10	7.7
2nd Layer	38.53	35.26	-	-

Figure 5.6: Plot and Values of Apparent and Real Conductivity of Horizontal Dipole Orientations along Itori Traverse 3 (Profile 6)



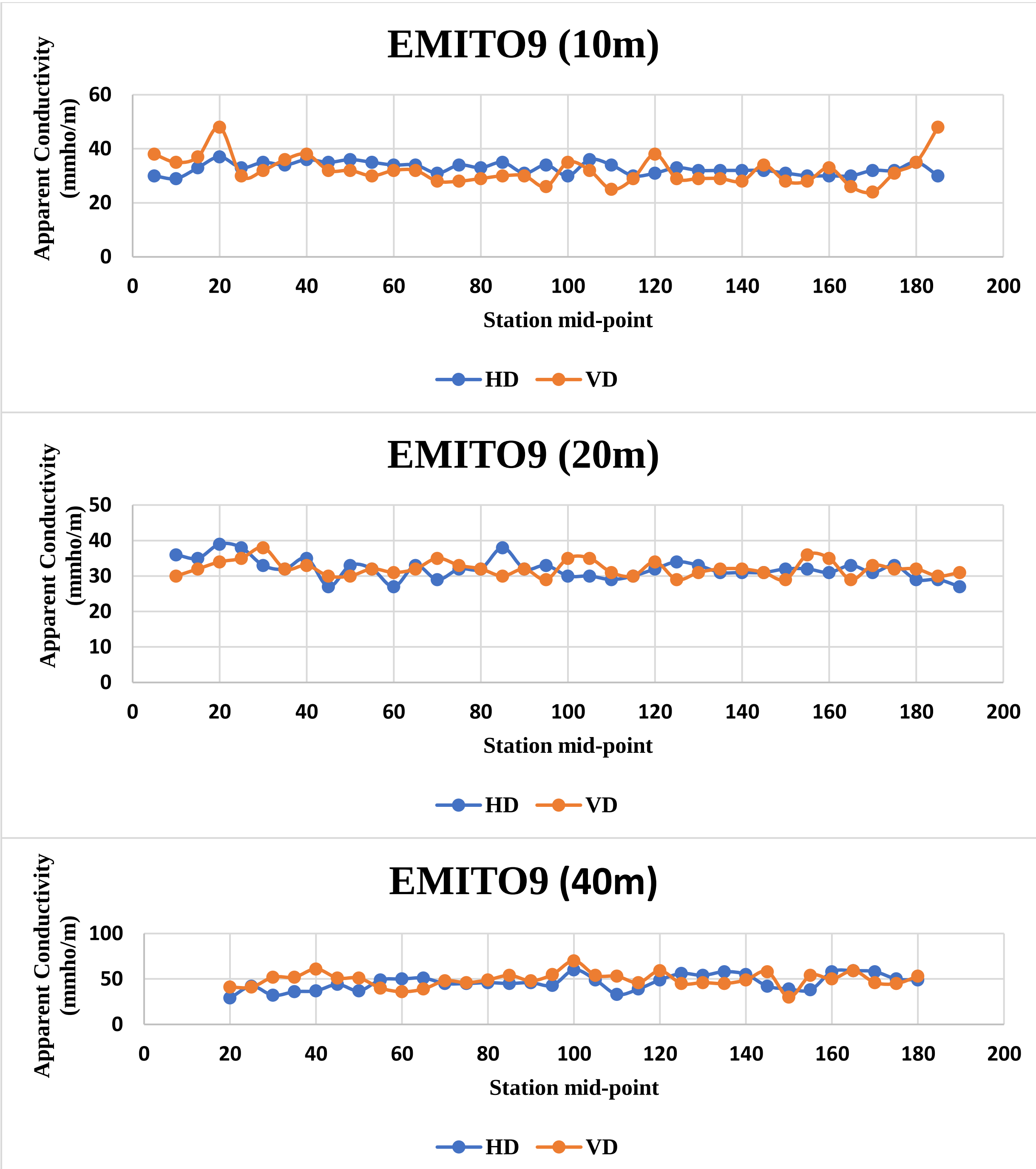
	True Conductivity (mS/m)		Depth(m)	
	HD	**VD**	**HD**	**VD**
1st Layer	34.54	34.24	7.8	10.45
2nd Layer	37	35.22	-	-

Figure 5.7: Plot and Values of Apparent and Real Conductivity of Horizontal Dipole Orientations along Itori Traverse 4 (Profile 7)



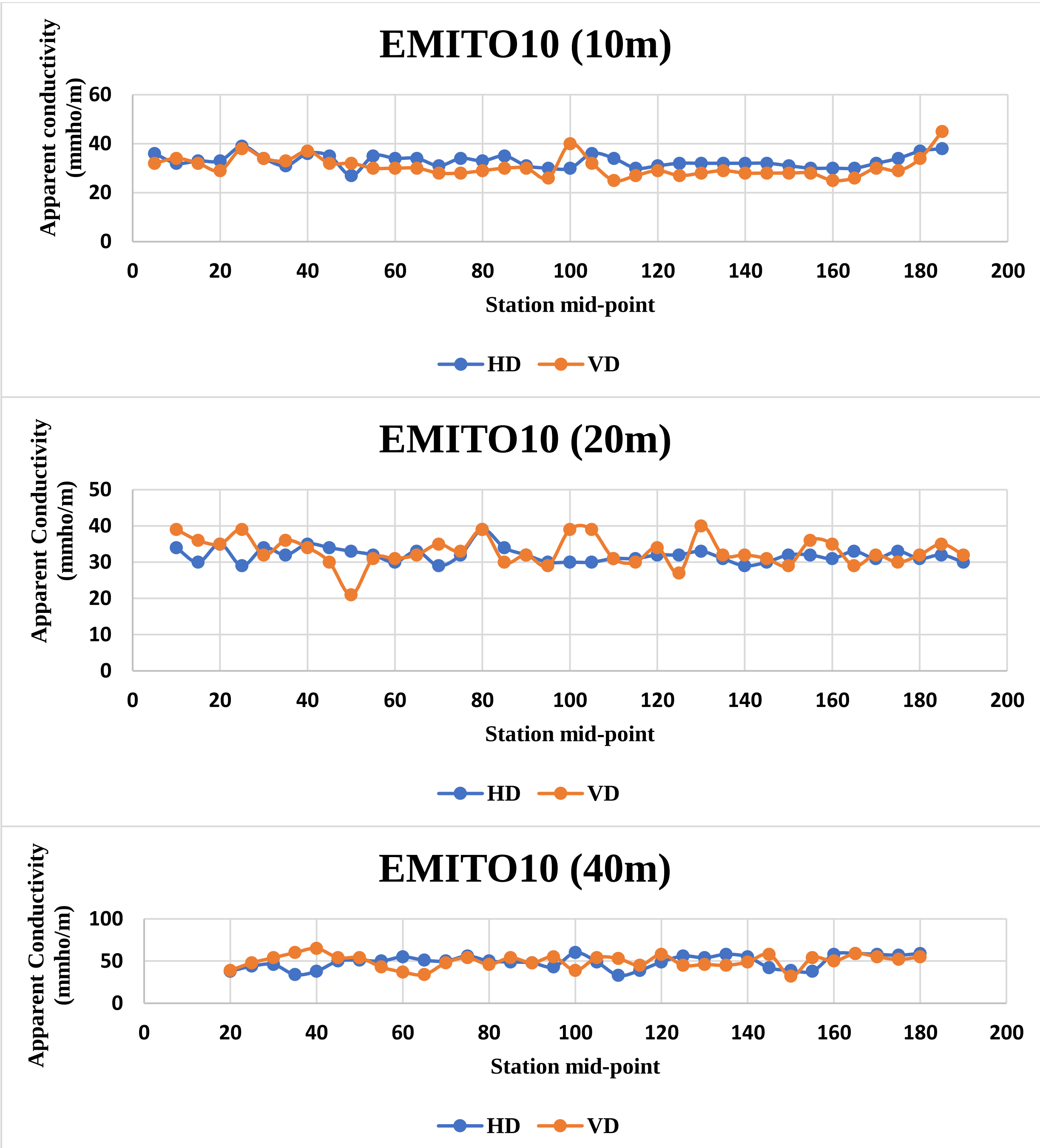
	True Conductivity (mS/m)		Depth(m)	
	HD	**VD**	**HD**	**VD**
1st Layer	25.41	29.1	11	12
2nd Layer	36.3	34.76	-	-

Figure 5.8: Plot and Values of Apparent and Real Conductivity of Horizontal Dipole Orientations along Itori Traverse 4 (Profile 8)



	True Conductivity (mS/m)		Depth(m)	
	HD	**VD**	**HD**	**VD**
1st Layer	35.03	32.13	5	17
2nd Layer	38.2	40.58	-	-

Figure 5.9: Plot and Values of Apparent and Real Conductivity of Horizontal Dipole Orientations along Itori Traverse 5 (Profile 10)



	True Conductivity (mS/m)		Depth(m)	
	HD	**VD**	**HD**	**VD**
1st Layer	33.35	31.69	12	9.8
2nd Layer	39.47	35.54	-	-

Figure 6.0: Plot and Values of Apparent and Real Conductivity of Horizontal Dipole Orientations along Itori Traverse 5 (Profile 10)

Profiles in EMITO2 may not suitable for groundwater developments as there are no characteristic features of coincident inflections on both the horizontal and vertical dipole curves. The Vertical Dipole Moment in the first layer exhibited the highest true conductivity and lowest true conductivity of 42.65 *mS/m* and 29.1 *mS/m* for EMITO1 and EMITO2 respectively and the corresponding Horizontal Dipole Moment exhibited the highest true conductivity of 36.0 *mS/m* and 25.41 *mS/m* for EMITO1 alongside EMITO2 and EMITO8 respectively while The Vertical Dipole Moment in the second layer exhibited the highest true conductivity of 45.62 *mS/m* and lowest true conductivity of 34.76 *mS/m* for EMITO1 and EMITO8 respectively and the corresponding Horizontal Dipole Moment exhibited the highest true conductivity of 44.0 *mS/m* and lowest true conductivity of 36.3 *mS/m* for EMITO3 and EMITO8 respectively. The results of the Electromagnetic conductivity survey of all the investigated locations of the study area predict the quality of the groundwater domain under investigation including the vulnerability of the conductive overburden of each of hydrostratigtraphic unit of the sedimentary formations and ultimately the aquiferous zones of the study area. The three frequencies seeking different investigation depths are used to outline shallow conductive structures probably connected to local water circulation. These results are also important in the delineation and delimitation of protected zones from possible contaminations. The study area is a typical ecosystem of varying industrial, agricultural, commercial and even cattle raising activities. It is well known that the pollutants generated from these activities are mainly transported through the surface water. It is then very important to protect the aquifer from these invading contaminants and superficial pollutants. The most efficient and economic way is to understand the natural overburden in order to reduce or eliminate the transport of pollutes through the aquifer. The spatial Distribution Itori subsurface conductivity across each profile and their corresponding subsurface True Conductivity variation across each surveyed Profile for first layer respectively shown in Figure 6.1 and Figure 6.2 and second layer are shown in Figure. 7.1 and Figure 7.2. Therefore, conductive and resistive characteristics of the overburden are very important and were partly one of the goals of this work.

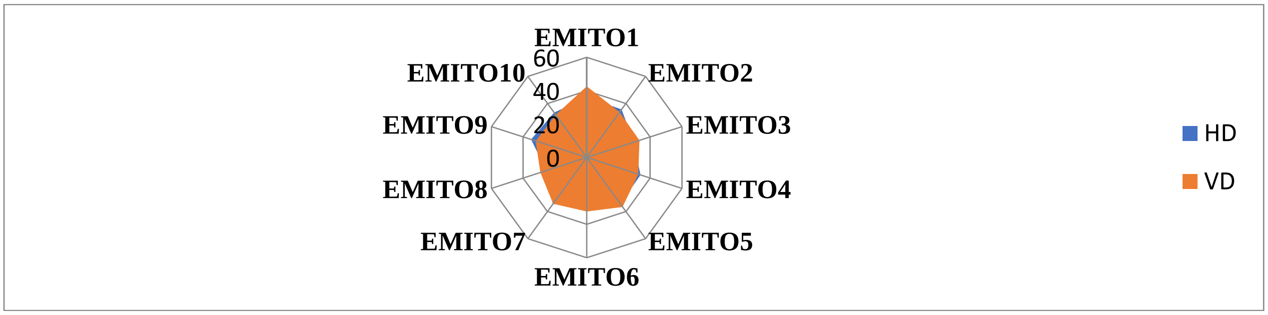


Figure 6.1: Distribution of Itori subsurface conductivity across each Profile for 1st Layer

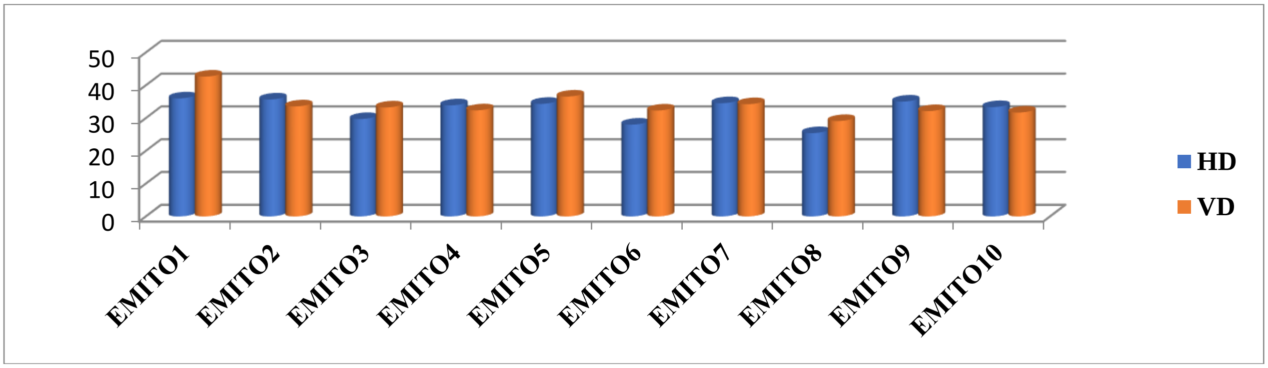


Figure 6.2: Itori Subsurface True Conductivity variation across each surveyed Profile for 1st layer

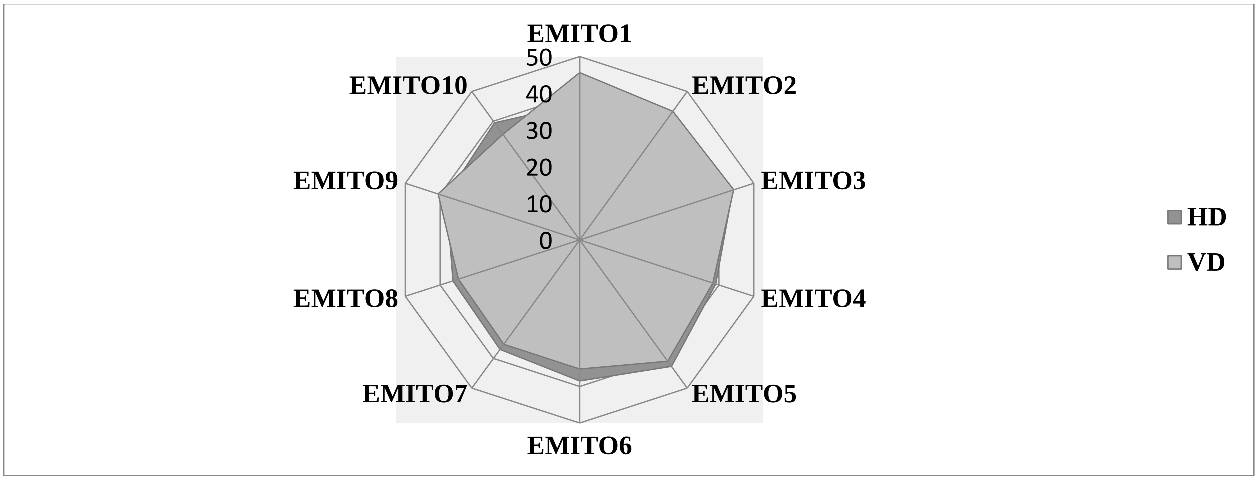


Figure 7.1: Distribution Itori subsurface True Conductivity across each Profiles for 2nd Layer

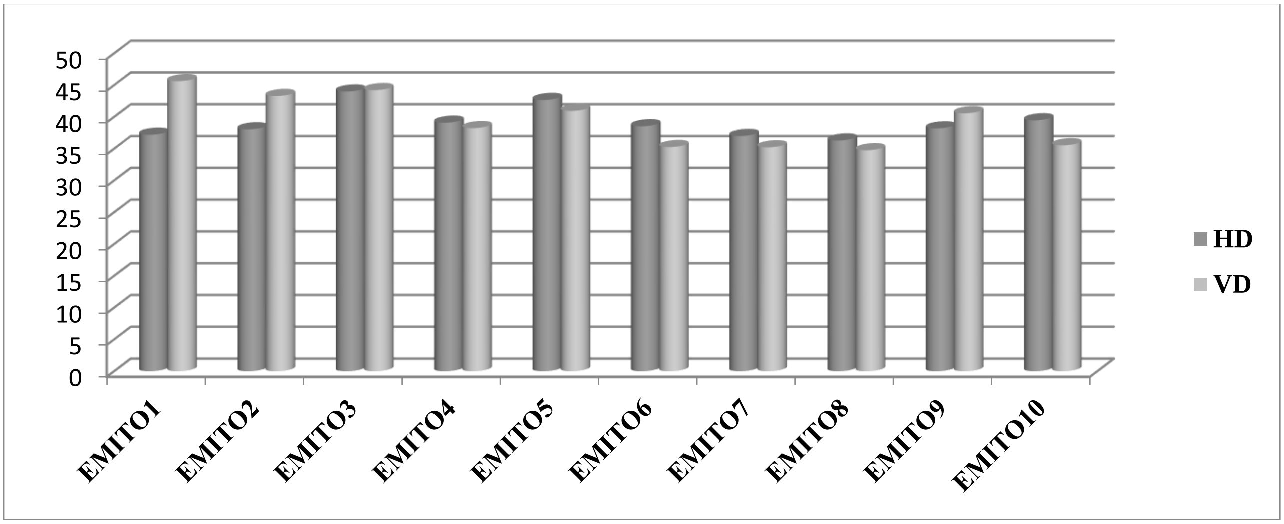


Figure 7.2: Itori Subsurface True Conductivity variation across each surveyed Profile for 2nd layer

CONCLUSION

The electromagnetic profiling surveys in the Itori communities have contributed to a better understanding of a typical sedimentary cover of South-West Nigeria. Interpretation of the EM profiles identified some conductive zones which were considered as priority areas for depth sounding. Sites with higher electromagnetic anomaly (high positive peaks) can be expected to be aquifers, implying locations suitable for the development of groundwater resources (Ugwu, and Nwosu, 2009). Based on these, the area could be categorized into high, intermediate and low groundwater potential. Analysis of the geophysical survey data revealed that the study area could play a significant role in providing adequate portable water for the rural dwellers. However, air- filled, altered or fissured bedrock, or predominantly clayey regolith may sometimes exhibit such anomalies (Ishola, 2019). The above indicates a probable zone of thick overburden with primary to secondary fractured aquifer system with a great depth extent. In this study, data from the geophysical investigation has provided qualitative information on the hydrogeologic framework and subsurface disposition of major aquifer units in the study area. Based on the results obtained from this survey, it can be concluded that integration of electromagnetic profiling is not efficient enough to determine the groundwater potential in the study area as it can only provide qualitative interpretation. It is, however, recommended that more sophisticated, effective and composite geophysical and hydrogeological investigations such as aerial remote sensing, seismic refraction, electrical tomography and depth probing electromagnetic instrument: ABEM WADI VLF instrument which detects fractures, the depth to the conductive zone and its dip and electrical resistivity sounding equipment: SAS 4000 (Lund Imaging System) for better imaging of the subsurface and to obtain data of better quality be further carried out within and other parts of the study area in order to have a comprehensive insight of groundwater potentials in the entire area.

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