

EVALUATION OF HYDROCARBON POTENTIAL USING LAND-BASED CONTROL SOURCE ELECTROMAGNETIC (CSEM) DATA IN MKPAT-ENIN LGA, NIGER DELTA, AKWA IBOM STATE, NIGERIA.

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ABSTRACT

Evaluation of hydrocarbon potential using land-based control source electromagnetic (CSEM) data in Nkpat-Enin LGA, Akwa-Ibom State, Nigeria, was carried out to map out prospective areas for hydrocarbons exploration. High resolution CSEM data were obtained using the Bayesian methodology to ascertain the viability for hosting and exploring hydrocarbon potential in the study area. Evaluation of hydrocarbon potential is very important before drilling in order to know risk reduction, cost effectiveness and the best exploration method and tools to use for drilling without potential threat to life and property in the study area in the future. Analysis made shows that there is a very good match between the data obtained from the geophysical parameters, particularly where the reservoirs are shallow as applicable to the study area. Results obtained revealed that the risks update for CSEM line at Nya-Odiong is greater when considering the probability of success and distance compared to other study areas. Evaluation made depicts large probability of brine, oil and natural gas reservoir in Nya-Odiong. As such, exploration of hydrocarbon potentials can be achievable in this study area. Comparing the Project Value, Prior Probability of Success and the Value of CSEM, results obtained suggest that, hydrocarbons will be drilled in the study areas when the initial prospect value is high and the initial probability value of hydrocarbon presence is high. The CSEM data will affect the decision reason being that the prospect (brine, oil and natural gas) can be drilled and in such cases, in the middle zone, the value of CSEM data will be as large as 50mUSD. There are accumulations of hydrocarbon potentials in the study areas and they are readily suitable for exploration. The stable growth of active hydrocarbon reserves ensures their stable production consistently. The CSEM technology is suggestive of having significant potential to increase exploration efficiency, if applied correctly.

Key Words: Hydrocarbon, potential, exploration, Nkpat-Enin, Niger Delta

INTRODUCTION

The study area, "Nkpat-Enin" lies between latitude 4°4'5"N and longitude 7°44'56"E. (Akwa Ibom State Geonames, 2009). Nkpat-Enin is located in the south south region of Nigeria and is a town and a Local Government Area (LGA) of Akwa Ibom State. It sits at an altitude of approximately 185 metres (607 ft) above sea level. Mkpata-Enin LGA has an area of 322.352 square kilometres (124.461 sq mi) and it's the second largest local government area in Akwa Ibom state. The LGA is located within the industrial belt extending from Eastern Obolo, Etinan, Oruk Anam, Onna, to Ikot Abasi. The population was 178,036 based on the 2006 census (Akwa Ibom State Geonames, 2009). The area is rich in oil and natural gas; oil was discovered in Ikot Akpa/Ekop as early as 1953 (Akwa Ibom State University of Technology, 2009).

With higher and higher requirements on hydrocarbons exploration from oilfields, the integration of EM has become an effective approach to solving complicated problems especially in 3D EM and higher precision hydrocarbon detection methods. Electromagnetic method can show the presence of large geologic anomalies such as anticlines, fault blocks and salt domes, even though there may not be surface indications of their presence (Abubarkar and Habashy, 2005).

In recent years, hydrocarbon exploration has been more and more difficult, but poses a challenge and an opportunity for land-based CSEM techniques to explore in the world (Zheng *et al.*, 2019; Zheng and Li, 2020; Safipour *et al.*, 2018). One of the challenges is that traditional 2D EM cannot satisfy the current hydrocarbon exploration in the study area, thus, 3D acquisition and processing are required for the evaluation of hydrocarbon potentials using land-based CSEM data in the study area. Another challenge is the investigation of deep igneous rocks which requires the contribution of geophysical methods among which CSEM technique is one of the most important means for which the study is centered only on the evaluation of hydrocarbon potentials using CSEM data. Another challenge is detecting lithologic reservoirs in the study area.

An in-depth understanding of hydrocarbon generation and expulsion characteristics can effectively improve the accuracy of resource evaluation and the prediction of favorable exploration zones which are important for petroleum exploration and development of source rocks (Wang *et al.*, 2020 & 2012). Several methods of extraction and analytical determination for total petroleum hydrocarbon (TPHCs) have been reviewed in the study area using different geophysical methods but this work will bring to lamplight the importance of evaluating hydrocarbon potential using land-based CSEM which has the capacity of revealing the type of hydrocarbon present in the study area for exploration.

This study is therefore aimed at effectively using the land-based CSEM data to evaluate the hydrocarbon potential of the study area and to shed more light on sediment thickness which is crucial to hydrocarbon exploration. The objectives of this work are to map out the prospective areas for brine, oil and gas exploration, analyze the spectral depth estimation of petroleum based on elevation, latitude and longitude.

MATERIALS AND METHOD

Maxwell's four equations describe the electric and magnetic fields arising from distributions of electric charges and currents, and how those fields change in time. They were the mathematical distillation of decades of experimental observations of the electric and magnetic effects of charges and currents, plus the profound intuition of Michael Faraday (Chen and Xue, 2006). The equations mainly give us the idea about how the electric and magnetic fields interacts with each other.

Equations that together form a complete description of the production and interrelation of electric and magnetic field are (Zheng *et al.*, 2019; Guo *et al.*, 2016)

$$\text{Gauss' law for electricity: } \oint \vec{E} \cdot d\vec{A} = \frac{q_{enc}}{\epsilon_0} \quad (1)$$

$$\text{Gauss' law for magnetism: } \oint \vec{B} \cdot d\vec{A} = 0 \quad (2)$$

$$\text{Faraday' law: } \oint \vec{E} \cdot d\vec{s} = -\frac{d\phi_B}{dt} \quad (3)$$

$$\text{Ampere – Maxwell law: } \oint \vec{B} \cdot d\vec{s} = \mu_0 \epsilon_0 \frac{d\phi_E}{dt} \quad (4)$$

where q = E.M charge, E = electric vector field, B = magnetic field, A is the area, and ϵ is the electric permittivity of free space or dielectric constant.

Equation (1) relates net electric flux to net enclosed electric charge, equation (2) relates net magnetic flux to net enclosed magnetic charge, equation (3) relates induced electric field to changing magnetic flux, and equation (4) relates induced magnetic field to changing electric flux and to current.

The study was conducted in Nya-Odiong, Ikot-Ekpa, Ikot-Etina and Asung all in Mkpato-Enin LGA of Akwa Ibom State, Nigeria. The survey was carried out on 160 stations for high frequency passive land-based CSEM and 180 stations for CSAMT. The sites for both methods coincide. A STRATAGEMEH-4 real-time system for passive source CSEM and two V6-A multipurpose receivers were used for data acquisition, including a T-30 system which was used for CSAMT transmitting. The STRATAGEMEH-4 records orthogonal electric and magnetic fields, which are used to obtain the tensor impedance for interpreting 2-D structures. This provides electrical conductivity imaging of the subsurface for depths between 10 meters and 1,000 meters. The electric field was measured by two pairs of titanium electrodes, while the magnetic field was measured by highly sensitive magnetic coils. The scalar survey mode was used in the CSAMT method. Seven C-C electrodes, a new kind of electrode made primarily from carbon, arranged in a line to cover six field sites, were used to record the data. To avoid the near-field effect, we chose the transmitter-receiver separation to be larger than 9 km, which is about ten times the maximum depth of the tunnel.

Land-based controlled-source electromagnetic system may experience two weaknesses when exploring for deeper conductors: poor coupling with the target and small signal-to-noise ratios (S/Ns), both of which reduce the quality and interpretability of the area. These weaknesses were addressed by evaluating an oval time-domain EM procedure. The coupling weakness was addressed through multiple transmitter locations and multiple receiver locations, and the S/N was increased by spatial tacking of measurement (from the various transmitter-receiver combinations). A field test of this procedure was undertaken. Reciprocity data indicated that the noise levels of the vertical component data we acquired were about $-0.004 \mu\text{V}/\text{Am}^2$. Spatial tacking of the data can reduce the noise levels by a factor of seven. This means that a small conductor previously only visible to 150 m could be seen to 275 m and a conductor visible to 300 m could be seen to 575 m.

The time required to collect all the transmitter-receiver combinations could be a challenge to this procedure-this time can be reduced using the principle of reciprocity and not repeating approximately reciprocal measurements. Also, visualizing and interpreting the large volumes of data collected using the procedure could be a challenge-this has been partially addressed by creating equivalent-dipole depth sections.

The Bayesian Methodology for integrating the use of land-based CSEM data for hydrocarbon exploration was adopted. However, computing the probability of hydrocarbon potential presence will be based on information obtained from the CSEM data. Meanwhile, the log interpretation will be obtained from the spectral depth estimation of CSEM data based on depths and GPS data.

RESULTS AND DISCUSSION

Basement Contour Map of the Study Area

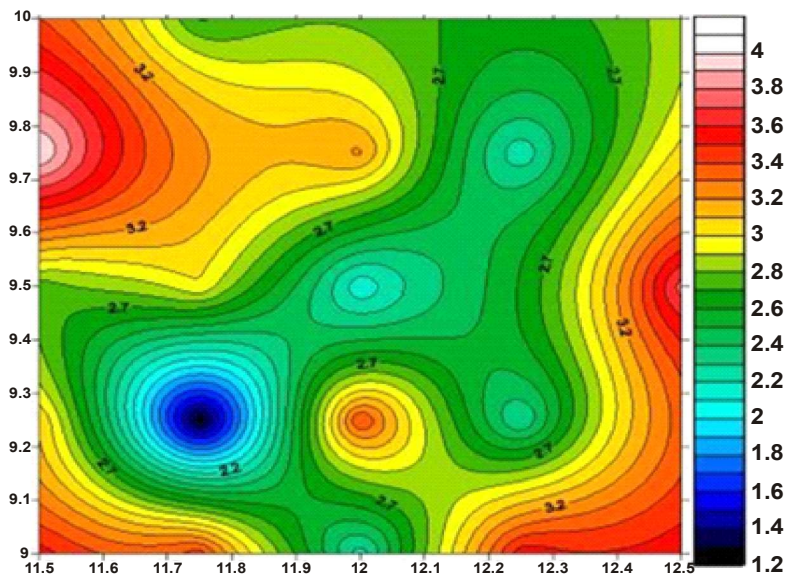


Figure 1: Basement Contour Map of Hydrocarbon Reserves in the Study Area.

The figure 1 shows the basement contour map of hydrocarbon reserves in the study area. The structural trend is predominant in the NE-SW direction of the study area. The pattern is dendritic and an indicative of lithological, structural and topographic differences. Areas of topographic heights of about 500 m of average are potential region for hydrocarbon potential due for explorations It is observed that these regions (Nya-Odiong, Ikot-Etina, Ikot-Akpa and Asung) have high lineament density with lots of lineaments crossing each other, an indicative of hydrocarbon potential availability and that the dominant structural trend in the NE-SW direction is in agreement with the Bayesian Methodology. This is in agreement with the explanations of An and Di (2016), in their investigation of geological structures with a view to HLRW disposal, as revealed through 3D inversion of aeromagnetic and gravity data and the results of CSAMT exploration.

Table 1: Commutative Geophysical Parameters for Hydrocarbon Exploration in the Study Area

S/N	Phase	Offset (km)	Probability of success	Distance (Km)	Project Value (mUSD)	Prior Probability of success	Value of CSEM (mUSD)
1	20	1.00	0.10	0.10	200	0.10	5.00
2	40	2.00	0.20	2.50	400	0.20	10.00
3	60	3.00	0.30	5.00	600	0.30	15.00
4	80	4.00	0.40	7.50	800	0.40	20.00
5	100	5.00	0.50	10.00	1000	0.50	25.00
6	120	6.00	0.60	12.50	1200	0.60	30.00
7	140	7.00	0.70	15.00	1400	0.70	35.00
8	160	8.00	0.80	17.00	1600	0.80	40.00
9	180	9.00	0.90	20.00	1800	0.90	45.00
10	200	10.00	1.00	22.00	2000	1.00	50.00

Phase (°) Vs Offset (Km)

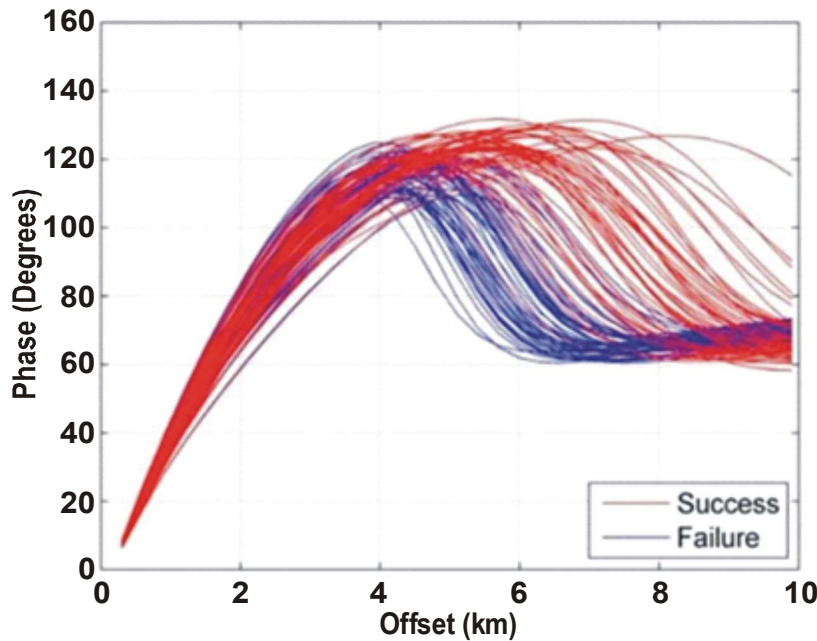


Figure 2: Signature for Multipurpose Brine and Gas Reservoir (success or failure) at Ikot-Akpa

The figure 2, shows the signature for multipurpose brine and gas reservoir at Ikot-Akpa. The red trend represents the success of hydrocarbons potential (TPHCs) reservoir while the blue trend represents the failure of hydrocarbons potential (TPHCs) reservoir in the study area. The red trend shows that the success of the multipurpose brine and natural gas are increasingly stronger than the failure. Thus, the positive strength (success) of the prospect becomes stronger as the phase increases. At a peak of 130 degrees, the success trend covers wide range of prospect thereby influencing the failure

trend to drop drastically. However, the exploration of hydrocarbon potentials at Ikot-Ekpa is realizable since the study area is rich in hydrocarbon potentials. From the figure, one could assert that there is a good match between the project phase and offset where the reservoirs are shallow.

CSEM Lines of Risk Update for Petroleum

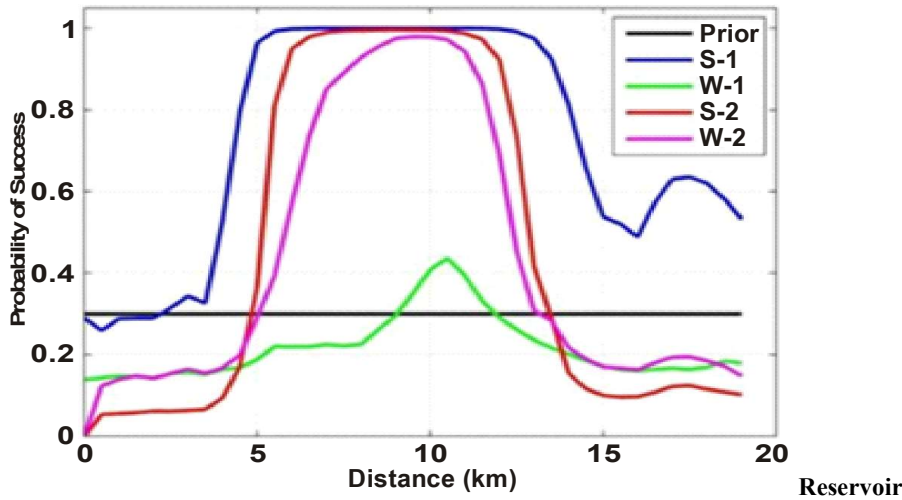


Figure 3: Risk Update for petroleum Reservoir CSEM Line at Nya-Odiiong, Ikot-Etina, Ikot-Ekpa and Asung.

The figure 3 shows the risk update for petroleum reservoir CSEM line at Nya-Odiiong, Ikot-Etina, Ikot-Ekpa and Asung. Depending on the probability of success with distance. S-1, S-2, W-1, and W-2 represent the risk update of Nya-Odiiong, Ikot-Ekpa, Ikot-Etina and Asung respectively. The black linear contour (prior) represents the boundary between the high and low probability of success. Analysis deduced from the figure 2 denotes that it is only Nya-Odiiong curve begins precisely at 0.29 very close to 0.3 which happens to be the boundary between the low and high hydrocarbon potential presence and drop above 0.5 while curves of other study area lies below 0.2, hence it could be predicted that Nya-Odiiong has large probability of success for petroleum reservoir compared to other study areas and is very suitable for exploration.

Project Value, Prior Probability of Success and Value of CSEM

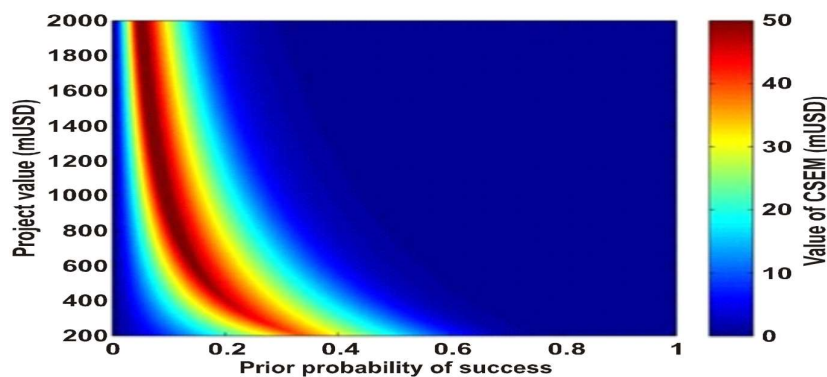


Figure 4: Relationship among project value, Prior Probability of success and Value of CSEM data in the study areas.

The value of the CSEM data is a function of price of drilling the prospect and the potential value as well as the initial estimate of probability of hydrocarbon presence which serves as a determinant factor for brine, oil and natural gas exploration. If the initial prospect value is small and the initial probability value of hydrocarbon presence is small, the CSEM data will not affect exploration. This is suggestive of the CSEM data having little value if the initial probability of hydrocarbon presence is large. More also, if the initial prospect value is small and the initial probability value of hydrocarbon presence is small, the CSEM data will not affect the decision reason being that the hydrocarbons prospect (brine, oil and natural gas) will not be drilled in the middle zone (Ikot-Ekpa and Asung) and the value of CSEM data will be as large as 50mUSD. This is in confirmation with the discussions of Kamureyina and Sillitoe, (2010) in their paper “Porphyry copper systems”. Figure 4 shows the relationship among project value, prior probability of success and value of CSEM data in the study areas.

Mass Magnetization and Magnetic Field

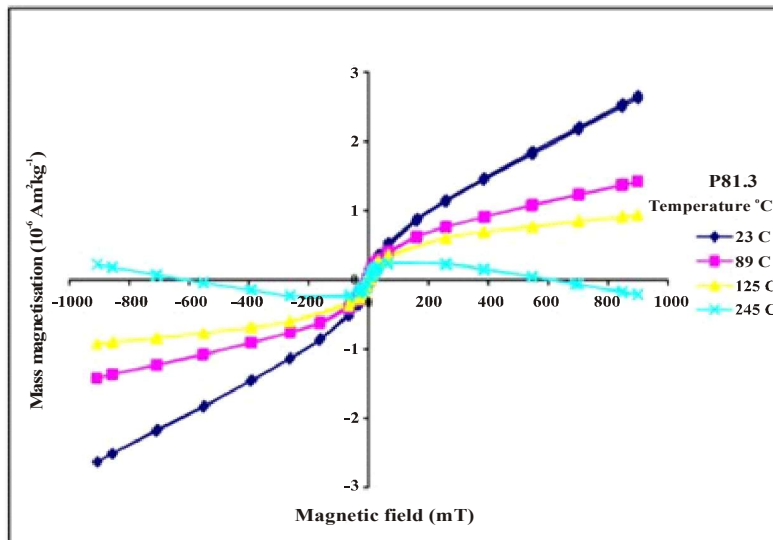


Figure 5: Plot of Mass Magnetization against Magnetic Field at Different Temperatures in the Study Area.

Spectral depth estimation is dependent on temperature, magnetic field and mass magnetization. Figure 5 shows the graph of the mass magnetization as a function of the EM features extracted from the four study areas (Asung, Ikot-Akpa, Ikot-Etina and Nya-Odiong) within Mkpato-Enin LGA at a low magnetic field of 0.2 mT. The green, yellow, purple and blue colors represent Nya-Odiong, Asung, Ikot-Ekpa and Ikot-Etina areas respectively. Nya-Odiong has a lower, positive mass magnetization and magnetic susceptibility at 245°C while Asung, Ikot-Ekpa and Ikot-Etina has higher positive mass magnetization and magnetic susceptibility at 125°C, 89°C and 23°C compositions respectively. The temperature is dramatically inversely proportional to the mass magnetization and susceptibility along the magnetic field. However, further increase in the temperature results in slight decrease in the mass susceptibility reaching a plateau. Thus in our high temperature synthesis (245°C) the maximum mass magnetization is observed for relatively

Zn rich materials apart from the major hydrocarbon potentials considered. This is in agreement with the results of Jang *et al.* (2015), who reported a maximum saturation magnetization at a Mn:Zn ratio of 1.5.

Magnetic Susceptibility of the Total Field

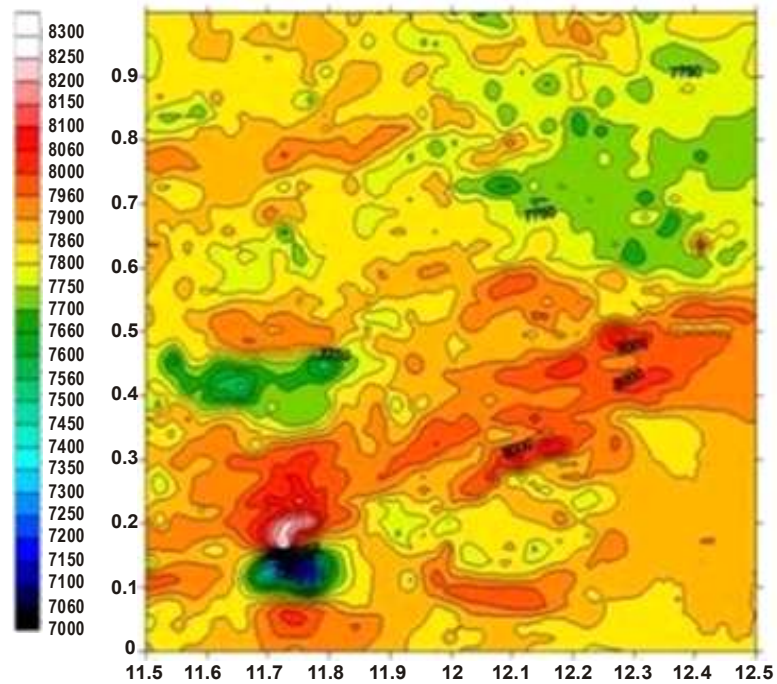


Figure 6 shows the magnetic susceptibility of the total field map of the study area.

It is observed that the dominant hydrocarbon potentials are in the NE-SW direction (figure 6) whose trend could indicate the Charcot fracture zone which is believed to be extending towards the West African region. The first to fourth degree residual (polynomial) maps which is not shown in this work, show small clusters which indicate igneous intrusions, granitic rocks, mineral bodies, rhyolite, granodiorites etc, outcropping at the surface. Also from the figure, we can suggest that the basement area will not be favorable for hydrocarbon prospecting because of the possible granitic intrusion and low sedimentary piles and should also be noted that trapped hydrocarbon will be baked as a result of contact metamorphism at the point of intrusion.

CONCLUSION

Evaluation of hydrocarbon potential using land-based control source electromagnetic (CSEM) data in Nkpat-Enin LGA, Akwa-ibom State, Nigeria, was carried out to map out prospective areas for hydrocarbons. Evaluation of hydrocarbon potential is very important before drilling in order to know risk reduced, less expensive and the best exploration method and tools to use for drilling without potential threat to life and property on the study area in the future. The stable growth of active hydrocarbon reserves ensures their stable production consistently.

Probability of success or failure of brine, oil and natural gas in the study area was compared using the CSEM Phase and CSEM Offset. Analysis made revealed that there is a very good match

between the data obtained from the geophysical parameters, particularly where the reservoirs are shallow as applicable to the study area.

From the study, it showed that the success rate for multipurpose brine, oil and natural gas at Ikot-Akpa is far greater than the failure rate and the results obtained revealed that the risks update for CSEM line at Nya-Odiong is greater when considering the probability of success and distance compared to other study areas. Evaluation carried out depicts large probability of brine, oil and natural gas reservoir in Nya-Odiong, suggesting achievable exploration of hydrocarbon potentials in the study area.

Also, from our analytical view, it is predicted that the CSEM data depends on the price of drilling the prospect, the potential value and the initial estimate of the probability of hydrocarbon presence. Evaluations were interpreted as a result of comparing the Project Value, Prior Probability of Success and the Value of CSEM. Results obtained suggest that, hydrocarbons will be drilled in the study areas when the initial prospect value is high and the initial probability value of hydrocarbon presence is high. As such, the CSEM data will affect the decision because the prospect (brine, oil and natural gas) can be drilled and in such cases, in the middle zone, the value of CSEM data will be as large as 50mUSD. There are accumulations of hydrocarbon potentials in the study areas and they are readily suitable for exploration.

In order to ensure accurate evaluation of hydrocarbons potential presence in the study area, resources should be moved to sources that are easier to locate but, are more difficult to exploit. Detailed estimation of petroleum reserves and resources should be carried out in the study area coupled with researchers carrying out works on the analysis of oil recovery factors, dynamics of oil and gas extraction in the study area and occasional re-evaluation of hydrocarbon reserves and resources with the involvement of new geological, geophysical, petro physical data, as well as using new methods should be adapted for research work on the study area.

Synthetic and real equivalent-dipole depth sections appeared very similar and illustrated that these images of the subsurface could be interpreted. However, better visualization techniques could be developed.

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