The Influence of Non-Collinear Electrodes Arrangement on a Two-dimensional Resistivity Survey Using Wenner Array

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**Abstract.** Conventional protocols employed by various multi-electrode resistivity systems are designed with the assumption that the survey lines are straight to ensure collinear electrode pairs. However, as most survey areas are characterized by surface constraints, it is rarely possible to carry out two-dimensional electrical resistivity tomography (2-DERT) measurement on a straight line. Therefore, 2-DERT surveys conducted on a surface constraint field requires shifting of some electrodes off the survey line, which implies a non-collinear electrodes arrangement. Hence, the result of such a survey is prone to false anomalies and in turn, wrong interpretation. This article aims to uncover the potential effect of non-collinear electrodes arrangement on 2-D resistivity survey. To achieve this goal, the data was acquired in four phases using Wenner array with all electrodes inline, one offline, two offline and three offline at stepwise distances, respectively. The inverse resistivity models obtained revealed slight to distinct variation of anomalies as two or more electrodes are offline at a distance >½ the minimum electrode spacing.

1. Introduction

Two-dimensional electrical resistivity tomography (2-DERT) plays an important role in many geophysical investigations involving groundwater exploration \([1,2]\) engineering site characterization \([3]\), mineral exploration \([4,5]\), detection of underground cavities \([6]\) and shallow archaeological investigation \([7]\). This is perhaps due to its cost-effectiveness and efficient data acquisition through the use of multi-electrode systems \([8]\).

Multielectrode resistivity meters employ conventional protocols such as Wenner, Wenner-Schlumberger, dipole-dipole etc for 2-DERT measurement. The protocol controls the switching between the various electrode pairs, and it is built with the assumption that the survey lines are straight to ensure collinearity of electrodes at each point of measurement. Of all the protocols, Wenner array is the most commonly used due to its good signal strength \([9,10]\), and it is employed for this study. The configuration of the array is shown in figure 1. Where I is the injected current, \(V\) is the measured voltage, ‘a’ is the electrode spacing, \(C_1\), \(C_2\) and \(P_1\), \(P_2\) are the current and potential electrodes respectively.

Various studies had been made with regards to the application of this array in subsurface investigation. For example, \([11]\) delineated leachate plume migration on a dumpsite in Ibadan (Nigeria) while \([12]\) used the method to characterize the subsurface of a sedimentary terrain for groundwater resource development and management. \([13]\) applied the method to detect underground mine galleries over Jharia coal field, India.
It is evident that the array is intensively used in 2-DERT for subsurface investigation. However, the fundamental assumption of collinear electrode pairs upon which the array was built, seems to be often ignored. Because most of the survey areas are characterized by surface constraints which could lead to shifting of some electrodes off the survey line during the data acquisition. This, therefore, distort the collinearity of the various electrode pairs and their uniform spacing. As such, the 2-D ERT result obtained is liable to false anomalies and false interpretation as well. This article aims to ascertain the potential effect posed by the electrodes offline on a 2-D resistivity tomography, since most of the survey areas appears not to conform with the underlying principle of the method.

2. Materials and Methods

2.1. Study area and geological setting
This research was conducted at Universiti Sains Malaysia (USM) main campus, Penang Island, Malaysia. The geological settings of the Island is in complex as it is primarily made of granitic rock (figure 2) [14]. USM consists mainly of quaternary sediments originating from the parent rock; as such, it is relatively homogeneous in composition. This factor influences the choice of the study area.
2.2. Data Acquisition

Multi-electrode resistivity meter (ABEM Terrameter SAS4000) was used to acquire the data for this research. The data acquisition was in four phases; these are: Wenner array with, (i) all electrodes inline (W-AEI), (ii) one offline (W-1EO), (iii) two offline (W-2EO) and (iv) three offline (W-3EO) electrodes respectively. In the first phase (W-AEI), measurement was made on a 40 m-long profile with 41 stainless steel electrodes at 1 m minimum electrode spacing. For the second phase, the survey set up of W-AEI was maintained, except electrode number 21 that was shifted perpendicularly off the survey line in a stepwise distance of 0.2 m increment (0.2, 0.4, …1.0 m) for each measurement. Similarly, electrode number 3, 35 and 1, 21 & 31 were perpendicularly shifted for phase three and phase four respectively. In all the phases, the input current was set between 1 and 100 mA. The acquired resistivity raw data downloaded from ABEM Terrameter SAS 4000 was converted into readable files using SAS 4000 utilities software. Thereafter, it was processed using the Res2Dinv software and Surfer 8 software. The former was used to perform inversion of the resistivity data while the later was used to enhance the visualization of the inverse resistivity models. Since the subsurface geology of the area is relatively homogeneous, the standard constraint least-square inversion algorithm [15] was applied in order to obtain the resistivity models.

3. Results and Discussion

The results obtained for all the four phases, are shown in figure 3-6 respectively. All the inverse resistivity model indicated high resistivity zone (> 1400 Ω·m) less than 3 m depth and low resistivity zone (< 1400 Ω·m) at depths greater than 3 m. The inverse model for the first phase (W-AEI) (figure 3), considered to be the true model for which the inverse models of the remaining three phases (W-1EO, W-2EO and W-3EO) were compared to in order to ascertain the effect of the non-collinear electrodes.

Figure 4a-f shows two-dimensional inverse resistivity models for the true model and the second phase which involve Wenner array survey with one electrode offline (W-1EO) at 0.2, 0.4, 0.6, 0.8 & 1.0 m distances respectively. Almost all the resistivity inverse models for W-1EO nearly match that of the true model. This implies that there is no significant effect on two-dimensional resistivity result obtained using Wenner array with only one electrode offline.

![Figure 3. Two-dimensional inverse resistivity model for the true model (W-AEI)]
Similarly, figure 5a-f depicts two-dimensional inverse resistivity models for the true model and the third phase which involve Wenner array survey with two electrodes offline (W-2EO) at 0.2, 0.4, 0.6, 0.8 & 1.0 m distances respectively. The geometries of the true model are partially resolved for the resistivity models of W-2EO. It is seen that the tomograms with offline electrode distance less than \( \frac{1}{2} \) of the minimum electrode spacing “a” are approximate to the true model. However, tomograms with offline electrode distances greater than \( \frac{1}{2} a \) shows slight variation of anomalies when compared to the actual model (figure 5).

In the same vein, the tomograms for the true model and the fourth phase (W-3EO) are shown in figure 6a-f. The range of resistivity values obtained is the same with those of the three phases discussed above. However, some of the tomograms for W-3EO show a distinct variation of anomalies as compared to the true resistivity model. For instance, the low resistivity zone with resistivity value less than 900 \( \Omega \)-m for the actual model, span from a distance of 9 m – 27 m at the bottom part of the tomogram (depth >3 m). It appears to split into two for almost all the tomograms of W-3EO (figure 6b-f). This is possibly due to the offline electrodes as the geology of the area is relatively homogeneous.
**Figure 5.** Two-dimensional inverse resistivity model comparison between (a) W-AEI, and W-2EO at (b) 0.2 m, (c) 0.4 m, (d) 0.6 m, (e) 0.8 m, (f) 1.0 m distances respectively.
4. Conclusion

In this paper, the influence of electrodes offline on a 2-D electrical resistivity survey profile was investigated. The inverse resistivity models assessment between W-AEI and W-1EO, W-2EO, & W-3EO respectively, revealed insignificant variation for all W-1EO and some of the W-2EO survey conducted with offline electrode distance $<\frac{1}{2}$ the minimum electrode spacing ($a$). However, slight variation occurs for the W-2EO survey with offline electrodes distance $>\frac{1}{2} a$. More so, a distinct variation of anomalies manifested for almost all W-3EO surveys. This study has shown that when two or more electrodes are offline in a two-dimensional resistivity survey layout, the data (result) is significantly affected. Therefore, resistivity survey using Wenner array with two or more electrodes offline is highly discouraged.

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