Identification of Palaeochannels of Mihe River: An Approach Based on the Integrated Geophysical Methods

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Abstract: Palaeochannel plays an important role in the economic construction. Geophysical methods are appropriate tool to identify palaeochannel. On the basis of analyzed formation genetic type of the study area, this study combining Vertical Electrical Sounding & High-density Electrical Resistivity Tomography were measured paleochannel and the results were compared with drilling information. The resistivity results strongly reflects the spatial distribution characteristics of stratum in the research area, where the palaeochannel is represented by the high-resistivity values which is in the range of 18-40Ω•m indicating, the lithology mainly as fine sand and silty-fine sand. It will establish the foundation for rational exploitation and comprehensive utilization of palaeochannel resource in future in the area.

1 INTRODUCTION

Palaeochannels (Wu and Zhao, 1993) are old river channel beds containing coarser unconsolidated deposits which are formed either during the course of dying of the river or deflection of the river channel in a different direction. The sand layers, with or without a clayey cover (of variable thickness) at top, generally form potential aquifers owing to better conductivity and availability of storage space in the interstices of coarser granular material. The palaeochannels also act as good groundwater recharge avenues and pathways for groundwater flow. Often the palaeochannels yield good quality water in comparison to the adjoining areas. Such palaeochannels can be used for sustainable groundwater development and management for different needs such drinking and irrigation.

Many researchers have earlier also studied palaeochannels through using different techniques. Especially the new techniques and methods have greatly improved the accuracy and depth of research in the last several decades (Wu and Zhao, 1993; Wu et al., 1991; Dave et al., 2002; Fu et al, 2008; Zhu et al. 2013; Cao et al. 2016). Geophysical methods provide some of the uncomplicated and reliable groundwater exploration techniques. As the research going in various fields, the conventional resistivity method is difficult to meet the work demand while High-density Electrical Resistivity Tomography arising. It is widely applied especially in recent years (Mauro et al. 2013; Wang et al. 2016; Dai and Xie 2015; Chen S et al. 2017).

The study area is located in Shouguang City, China. It is in downstream of the Mihe River alluvial fan (North of the Mount Tai and the Mount Yi, South of Laizhou Bay, Figure 1). Because of the Mihe River erosion forms vast and flat plain where Quaternary is thick and continuous. It is composed of clayey sand mainly (Han,1996). Under the influence of the Ice Age in geological time Mihe River forms paleochannel (Han et al. 1999a). Its mainstream belt is mainly composed of gravel, sand and silt, the top and bottom plates are clay or loam. The Mihe River palaeochannel is the main enrichment area of groundwater. In the 1970s the saltwater intrusion occurred in the area. As the main secondary landform, palaeochannel is the main channel of saltwater intrusion and also the fastest intrusion, the most complex changes and the worst

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affected landform units (Han, 1996; Han et al. 1999b). Due to the over-exploitation of groundwater, three large-scale regional groundwater funnel areas（average groundwater level about -58m）centered on Hualong, Shengcheng Street and Luocheng Street have been formed. Therefore saltwater intrusion is gradually intensified.

In order to meet the challenges arising out of the crisis in water supply sector and saltwater intrusion in the fresh water aquifers, it has been imperative to map the palaeochannels of the rivers, which might host fresh water. For this purpose this study will combining Vertical Electrical Sounding & High-density Electrical Resistivity Tomography identify palaeochannel. The results will be compared to the information obtained in the exploration drilling.

2 METHODOLOGY

Affected by saltwater intrusion, groundwater in the area is divided into the northern saltwater zone, the middle salty-freshwater transitional zone and the southern freshwater zone (Zhao et al. 2000). The survey lines is laid from west to east according to the boundary of saline water & freshwater and the direction of the road, as shown in Figure 1. Based on the respective advantages of the two methods and the preliminary determination of the distribution and direction of palaeochannel, firstly we use One-dimensional Electrical Sounding in the "macro" to detect palaeochannel information; then High-density Electrical Resistivity Tomography is conducted in areas with palaeochannel response according to the first step exploration results.

2.1 Vertical Electrical Sounding

Vertical Electrical Sounding (VES) is an electrical exploration technique, which by changing the pole pitch of AB and MN to control detection depth in artificial electric field to obtain the vertical variation rule of the rock resistivity characteristic at the sounding point (Figure 2). The collection of VES data uses DZD-6A multi-function direct current electrical prospecting apparatus with symmetrical quadrupole devices according to Table 1 data layout polar distance. This is 94 sounding points in all (Figure 1).

2.2 High-density Electrical Resistivity Tomography

High-density Electrical Resistivity Tomography (ERT) is an array of exploration method based on conventional resistivity method. The measuring principle is identical to VES, except that ERT electrode arrangement completed once and more collecting data along with high efficiency can more intuitively reflect the characteristics of the underground space electrical abnormal body [8].

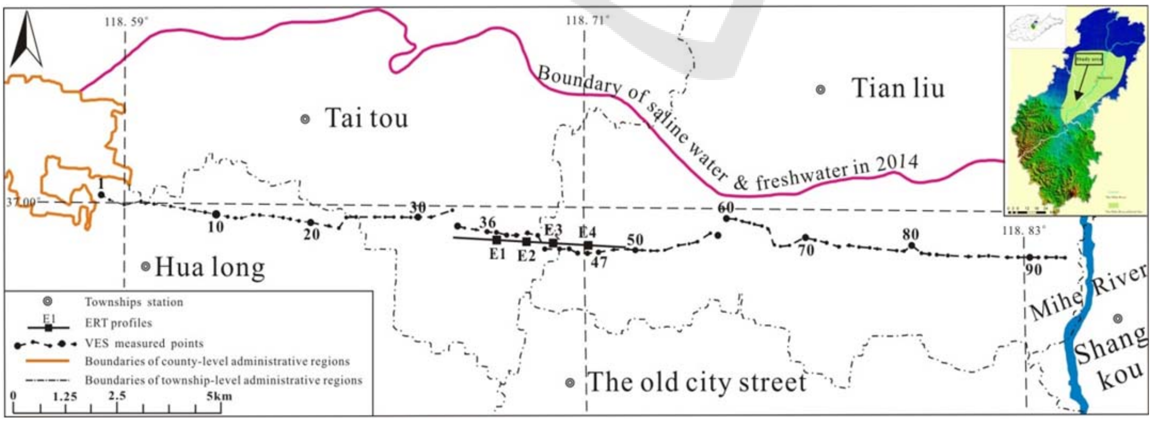

Figure 1: Illustration map showing location of the study area and measured points & profiles.

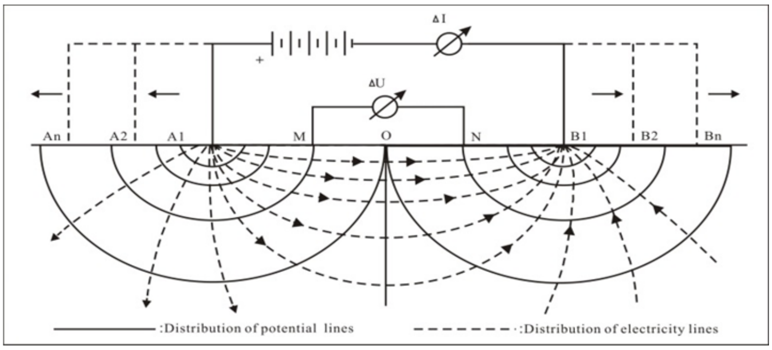

Figure 2: The schematic diagram of VES.

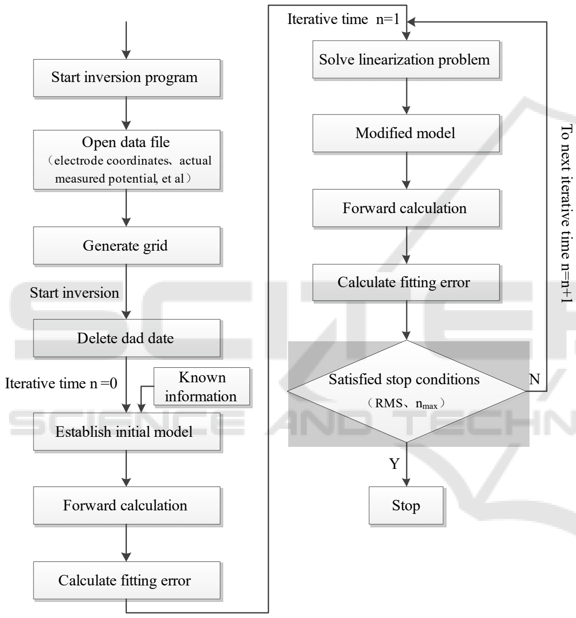

Figure 3: The flow diagram of resistivity inversion.

The collection of ERT data uses 61-channel FlashRES-UNIVERSAL ultra-high-density direct current electrical exploration system. The system uses advanced full-waveform ZZ data acquisition device breaking through conventional data acquisition method. In the electrode system composed of 64 measuring electrodes any one of AB supply electricity forms an electric field, MN can measure 61 potential (difference) data at the same time. Therefore when A and B composed of odd and even numbered electrodes respectively, ZZ device can obtain 32×32×61=62464 data each data acquisition.

According to the results of VES, it is preliminarily assessed that the palaeochannel response exists at the locations 36#～42# and 44#～47#. To further understand the spatial distribution of palaeochannel, ERT measurements were performed near this location. Figure 1 shows four profiles E1～E4 in total using full-waveform ZZ data acquisition device. Each profile is arranged with 64 electrodes, the unit electrode distance is 6m, and effective measuring line length is 378m.

The collected data of VES and ERT can calculate apparent resistivity ρ_s according to the following formula.

$$\rho_s = K\frac{\Delta U_{MN}}{I}, \tag{1}$$

$$K = \frac{2\pi}{\frac{1}{AM}-\frac{1}{BM}-\frac{1}{AN}+\frac{1}{NB}}, \tag{2}$$

Where ΔU_{MN} is potential difference between M and N (V); I is current between A and B (A); K is device coefficient; AM、BM、AN、NB are distance between electrodes respectively (m).

Due to heterogeneity and anisotropy of the actual stratum, ρ_s is not enough to reflect the electrical characteristics of the medium. Therefore, the true resistivity of the medium is calculated by the least square inversion method. The inversion process is shown in Figure 3.

Table 1: Data acquisition list of VES (Unit: Meter).

Sequence Number	AB/2	MN/2	Sequence Number	AB/2	MN/2
1	2.5	1.5	8	25	4
2	4	1.5	9	32	4
3	6	1.5	10	40	4
4	9	1.5	11	50	4
5	12	1.5	12	60	6
6	16	1.5	13	74	6
7	20	1.5	14	90	6

3 ANALYSIS AND DISCUSSION OF RESULTS

3.1 Analysis of VES Results

Sand and clay perform high and low resistivity respectively in palaeochannel sediments. Figure 4 shows VES resistivity curves after inversion of 36#～42#、44#～46# sounding points.

Figure 4 shows the "K" sounding curves carried out in the area. It indicates three different electrical layers vertically. Numerically, the curve is characterized by high center and low sides. The high and low resistivity zones are caused by enrichment of sand and clay respectively. This shows that the sounding points have palaeochannel distribution characteristics, and the corresponding lithology from top to bottom is clay - sand - clay.

From resistivity values and distribution of curves, it is evident that the maximum resistivity is 40Ω•m (40#, 41#) and the minimum is 16Ω•m (37#). The maximum is 2.5 times the minimum. The obvious contrast of resistivity indicates that there are different electrical strata at the sounding points. According to the range of resistivity values of clay & sand, all of the electrical sounding curves show an increasing trend at 18-20Ω•m, which indicates the existence of sand layer. With deepening of VES dipole depth, the resistivity increases to the maximum and then decreases gradually, which is caused by disappearance of sand and appearance of clay. Therefore the enrichment of sand characteristics in palaeochannel can be inferred based on characteristics of the curves. Table 2 shows characteristics of palaeochannel sand layer deduced from sounding curves.

Table 2 shows that the average buried depth of the top of sand layer (as deduced from the 10 electrical sounding curves) is 9.9m; the maximum depth of 16m (36#, 39#) and the minimum of 4m (44#). The average of bottom depth is 45.2m, the maximum depth is 80m at 40# sounding point and the minimum is 16m at 46#. It is deduces that the average sand thickness is 35.3m ,the maximum thickness is 58m (39#) and the minimum is 10m (46#).

3.2 Analysis of ERT Results

Figure 5 shows resistivity spatial distribution of the ERT profiles E1～E4 after inversion. The non-uniform distribution of resistivity in profiles indicates spatial heterogeneity in the stratigraphic lithology. Four profiles on the structure show overall three layers of "low - high - low " resistivity from top to bottom. This is consistent with the features reflected by VES.

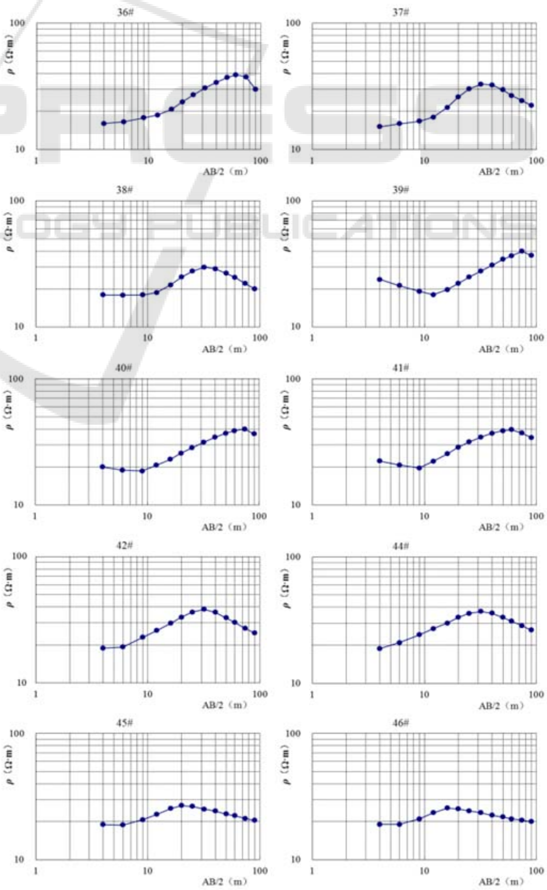

Figure 4: The graphs of VES.

Table 2: The inference statistical table of the palaeochannel characteristics of sand layer.

Method	Sand features (m)	Serial number of sounding points										Average
		36#	37#	38#	39#	40#	41#	42#	44#	45#	46#	
VES	Top depth	16	15	12	16	9	9	6	4	6	6	9.9
	Bottom depth	68	35	33	74	80	60	32	32	22	16	45.2
	Thickness	52	20	21	58	71	51	26	28	16	10	35.3
ERT	Top depth	18	15	12	22	7	8	5	3.5	5	6	10.1
	Bottom depth	70	35	32	78	78	59	30	29.5	22	14	44.8
	Thickness	50	20	20	56	71	51	25	26	17	8	34.4
Re (%)	Top depth	11.8	0.0	0.0	21.6	25.4	11.8	18.3	0.5	18.3	0.0	2.0
	Bottom depth	2.9	0.0	3.1	5.3	2.5	1.7	6.4	8.1	0.0	13.4	0.9
	Thickness	3.9	0.0	4.9	3.5	0.0	0.0	3.9	7.4	6.0	22.5	2.6

The resistivity values obtained by ERT are slightly less than VES, the maximum is 38Ω•m and the minimum is 3Ω•m. The maximum value is the same as VES. However the minimum value has a certain difference between them. It may be due to amount of data collected, difference of data values and regionalization of inversion process between them and others. Based on collected data, the criteria for dividing clay and sand is 18Ω•m. The calculation results of two methods are shown in Table 2. The location of VES sounding points in ERT profiles is shown in Figure 5.

Table 2 shows that the average buried depth at the top of the sand layer estimated from the ERT profiles of the corresponding location is 10.1m, the relative error (σ) with the VES inference is 2.0%, the absolute error (e^*) of other sounding points is not more than 2m except for 39# (e^*=4m) and the results of 37#, 38# and 46# is same to VES inference. The estimated bottom sand depth is 44.8m, σ with the VES inference is 0.9%, the absolute error of other sounding points is not more than 2m except for 39# (e^*=4m). The σ of 36#, 37#, 38#, 40#, 41#and 45# is less than 5% and the results of 37#and 45# is same to the VES inference. This implies that the results of two methods are basically in agreement. The top and bottom positions of 39# are 4m deeper than the VES result. From continuity of spatial distribution in the high resistivity region of ERT profiles, the result of ERT is more reliable. The average thickness of the sand layer estimated is 34.4m, with σ of 2.6% from the VES results. The largest σ is located at 46#, followed by 44# and 45# are 7.4% and 6.0% respectively. Others are within 5% and 37#, 40# & 41# are 0.

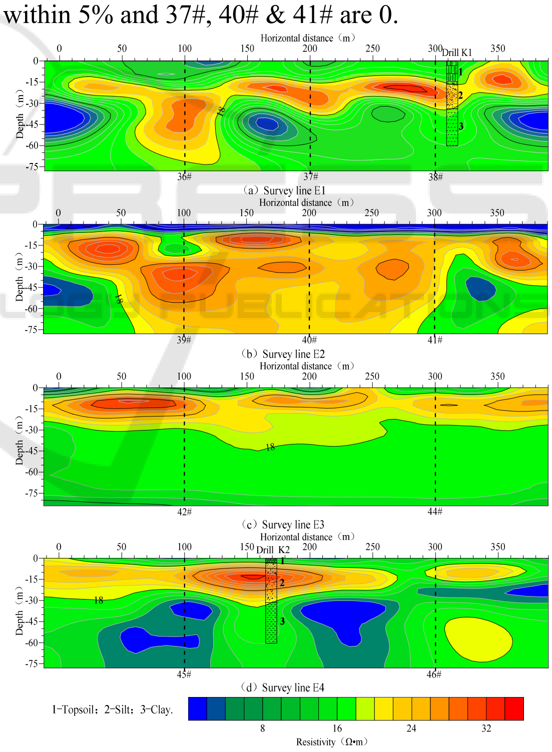

Figure 5: The resistivity profiles of ERT and drilling information of K1 & K2.

Through the above comparative analysis, ERT and VES can more conclusively deduce the information of clay layer and sand layer in the stratum except for 44#. Profile E1 show that the sand layer in other areas are mainly enriched in the stratum within a depth of about 15m except for the sand layer exposed at 345m-357m. The thickness of sand layer at 65m-125m is about 50m, and the thickness of other areas is about 15m. The location of Profile E2 is the main enrichment zone of the sand layer with a depth of about 8m. The thickness of the sand layer is about 25m at 0-50m and 350m-390m. The middle area is fully enriched with sand in exploration depth and extends to deeper. The typical "U" type distribution is in accordance with sedimentary structure of palaeochannel. The spatial distribution of sand layer at profile E3 is more uniform. Except for at 225m-260m and 360m-390m near the surface, the average sand depth in other areas is about 5m and the average thickness is about 24m. There is a discontinuity in the sand space at profile E4, which occurs at 270m-290m. The sand is mainly concentrated at 0-270m, the average depth is about 5m and the average thickness is about 22m. There is a sand lens body at 290m-370m with an average depth of about 5m and a thickness of about 10m.

3.3 Comparative Analysis of Exploration Drilling Results

In order to further verify characteristics of palaeochannel, this study arranged K1 & K2 drilling lithological data on E1 & E4 profiles respectively (Figure 5). The comparison of two results shows that high conformity between them and reliability of this integrated geophysical method.

4 CONCLUSIONS

Based on the integrated geophysical methods of VES & ERT and stratum differences in resistivity parameters, prospective palaeochannels have been identified. The results of geophysical methods were in accordance with the drilling data. It will establish the foundation for rational exploitation and comprehensive utilization of palaeochannel resource in future in the area.

The geophysical methods show the sand layer in palaeochannels reflected by high resistivity which is in the range of 18-40Ω•m in the average buried depth of about 10m. The buried depth in the middle is deep, the depth at both ends is shallow, and the average sand thickness is about 35m. The typical "U" type distribution is in accordance with the sedimentary structure of palaeochannel. The clay in palaeochannel reflected by low resistivity which is in the range of 5-18Ω•m. It constitutes the top & the bottom floor and protection structure of palaeochannel.

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