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El-Qady, Gad
National Research Institute of Astronomy and Geophysics(currently postdoctoral feilow of JSPS)

Metwaly, Mohamed
National Research Institute of Astronomy and Geophysics

El-Galladi, Ahmed
Geology Department Faculty of Science, Mansoura University

Ushijima, Keisuke
Department of Earth Resources Engineering : Professor

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# Evaluation of Peat Formation Using Geoelectrical Methods at Nile Delta, Egypt

by

Gad El-QADY[1,*], Mohamed METWALY[1], Ahmed El-GALLADI[2]
and Keisuke USHIJIMA[3]

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## Abstract

A peat layer has been encountered in the subsurface Holocene sediments of eastern part of the Nile delta at depth ranging from 5 to 13 meters and the maximum thickness of 3 m. The peat is considered as the worst kind of foundation material that may encounter in the substrata and is often unstable for supporting any kind of structure; hence cause hazard for infra structures in the area. This study aims to investigate the credibility of the available surface geophysical tools in detecting the vertical and lateral extensions of peat layer at two sites in Mansoura city, where considerable thicknesses of peat layer are recorded by test borings. The resistivity tomography measurements simultaneously with Induced Polarization survey have been conducted along two profiles. In addition, high resolution Transient Time Domain electromagnetic soundings and Self Potential measurements were also conducted along the same two profiles.

The shallow water saturated strata could affect the accuracy of the geoelectrical interpretation. However, the available lithological logs in the survey site with the multiple geophysical data could help in constraining the peat layer boundaries during data processing steps. The integrated results clearly depict the peat layer of high chargeability and relatively low resistivity, than the surrounding clay layers. A further geophysical survey to delineate the extensions of peat layer in the Nile Delta is proposed to eliminate the risk, such as a subsidence, affecting the infra structure in the area.

**Keywords:** Peat formation, Geoelectrical resistivity tomography, TDEM, SP, Nile delta

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[1] National Research Institute of Astronomy and Geophysics, 11722 Helwan, Cairo, Egypt
[*] currently postdoctoral fellow of JSPS
[2] Geology Dept. Fac. of Science, Mansoura University, Mansoura 35516, Egypt
[3] Professor, Department of Earth Resources Engineering

## 1. Introduction

Large amount of plant material must be accumulated and preserved to facilitate of peat forming. To complete the peat-forming process, it is necessary to have coverage of the accumulating plant debris by stagnant water to prevent its oxidation and destruction. Such geologic conditions were available in the area of Nile Delta during the past 10000 years[14]. A peat layer has been encountered in the subsurface Holocene sediments of eastern part of the Nile delta at depths ranging from 5 to 13 meters. The maximum thickness of peat (3 m) has been recorded around Mansoura city, and decreases gradually in a configuration parallel to Damietta branch of the Nile River, (**Fig. 1**).

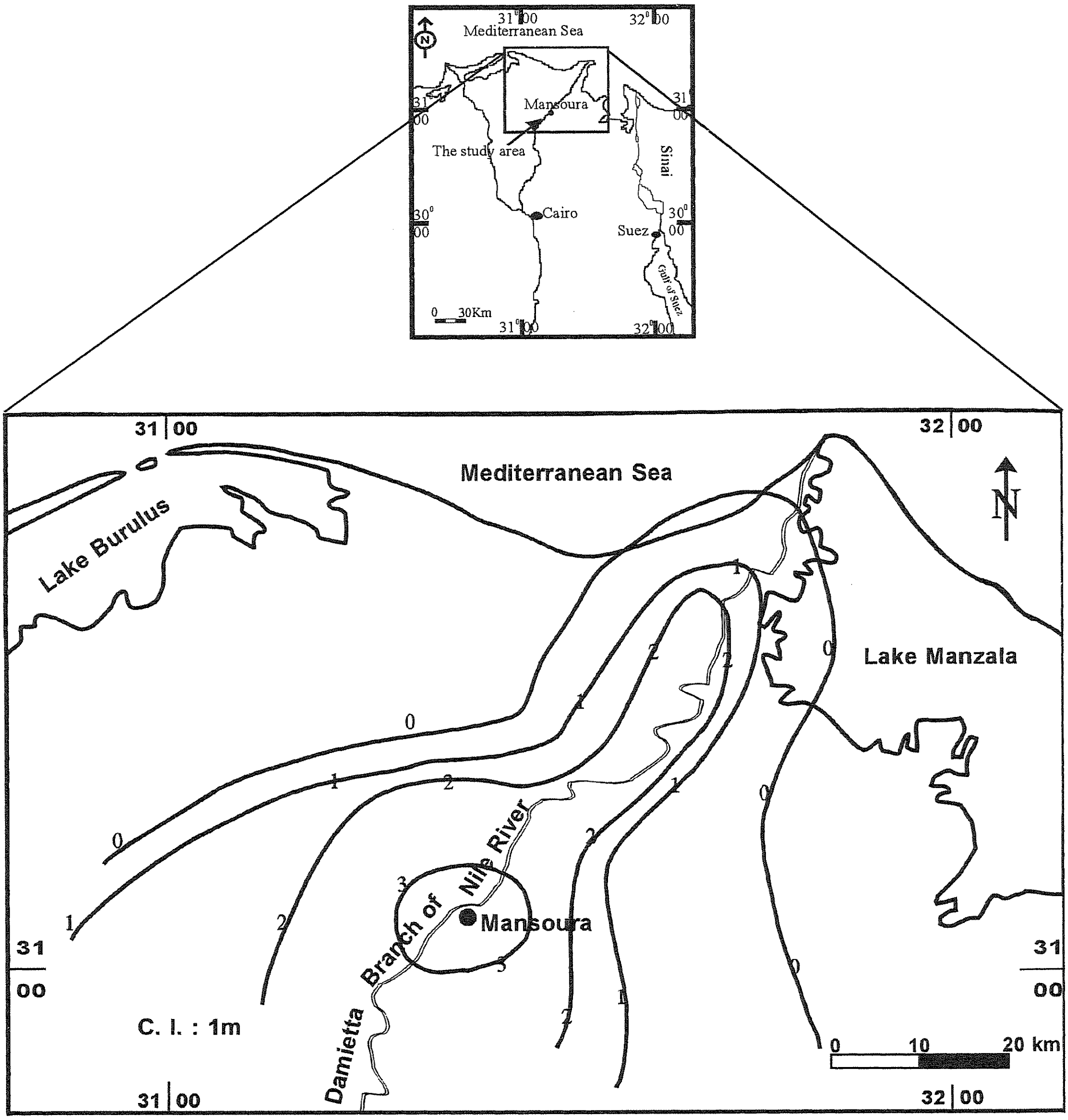


**Fig. 1** Location map of Mansoura city and Iso-pach contour map of peat in Holocene sediments of Eastern Nile Delta, Egypt (modified after Hegab and Bahloul, 1987).

From the engineering point of view, peat is considered as the worst kind of foundation material that may encounter in the substrata. Because of its extremely high compressible nature and its low shear strength, it is often unstable for supporting any kind of structure [12]. Solutions for subsidence problem based on engineering considerations are very expensive and complicated. Such solutions include replacing the peat with inorganic materials, carrying the foundation supports down to more stable strata. In this case the corrosive effect chemicals mixed with peat (e.g. sulphates) has to be considered; hence addition of stabilizing materials to improve the engineering properties of peat is necessary. However, it is impossible to dig all proposed sites for the foundation. Suitable geophysical tools may give good information about location, depth and thickness of the peat, which would help the engineers in selecting the best site for the desired constructions. Generally, according to the nature of the survey site and the specific objectives of the study, the most appropriate geophysical method is chosen to investigate the physical properties of the subsurface. Moreover, the spatial and temporal sampling intervals should be carefully selected to give the required depth of penetration and resolution. Selection of these intervals may require some idea about the nature, depth and size of the target.

In this study we tried to investigate the credibility of the available surface geophysical tools in detecting the peat formation at Mansoura city, eastern Nile Delta, where the maximum thickness of peat is recorded by borings. Two test sites have been selected, nearby two boreholes recently drilled at the main campus of Mansoura University (**Fig. 2**), for conducting the survey.

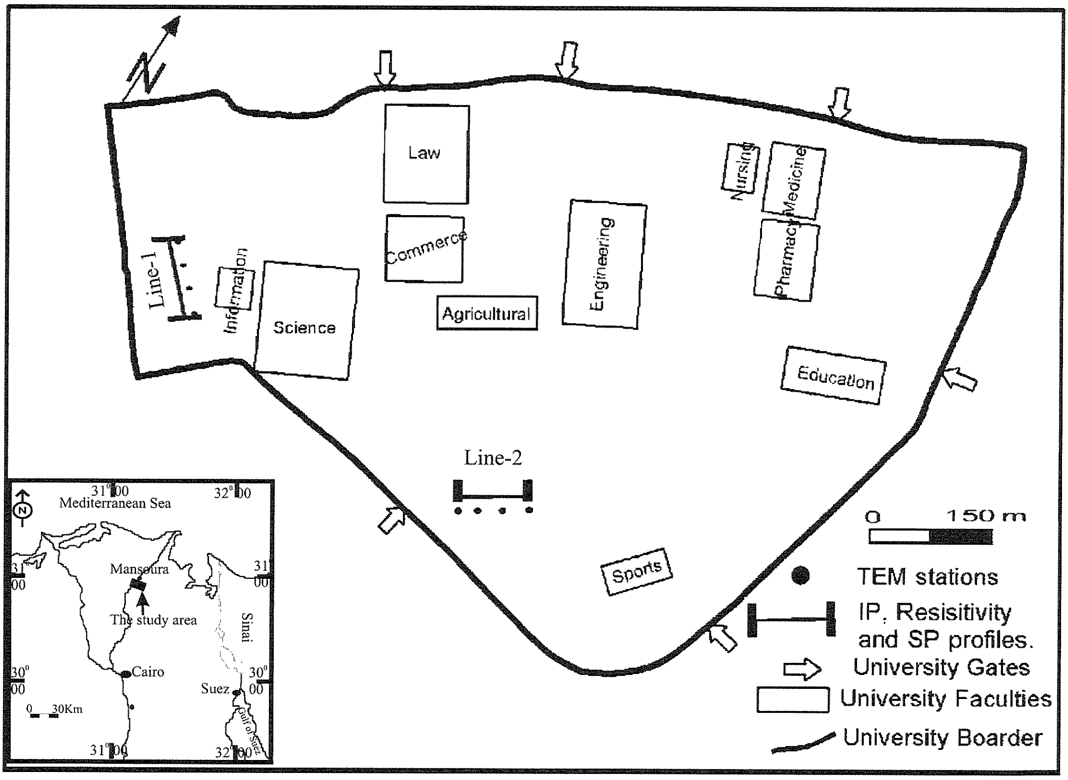


**Fig. 2** Location map of the test sites and boreholes at the main campus of Mansoura University.

## 2. Geological setting and peat formation

### 2.1 Geological setting

The Nile Delta area has been subjected to many geological investigations[2,14,24,25,26,30]. With these studies valuable information and abundant data have been established concerning the stratigraphy, hydrogeology and depositional history of the subsurface Quaternary sequence. The Quaternary subsurface of the Nile Delta, up to 1000 m depth, has been subdivided into Bilqas and Mit Ghamr Formations[24]. Bilqas Formation (Holocene) covers the whole Delta and its fringes with maximum thickness of 77 m and made up of alternating layers of sand, silt and clays which may include peat formation. While, Mit Ghamr Formation has the maximum thickness of about 970 m and represented by coarse sands with minor gravel and clay interbeds[29].

Hydrogeologically, the Quaternary succession in the Nile Delta can be differentiated into two water-bearing units[26]. The upper cap muddy bed of Bilqas Formation acts as aquitard and the lower thick sand sequence of Mit Ghamr Formation form the huge aquifer of the Delta. The sedimentary nature and hydrogeological characteristics of the Quaternary sequence in the Nile Delta vary from one site to another depending on sea level fluctuations, fluvial and marine processes and the nature of drainage basins which deliver water and sediments.

### 2.2 Origin of peat layer

Large amount of plant material must be accumulated and preserved to facilitate of peat forming. High primary productivity on land became possible only after the advent of higher plants with self-supporting skeletons, which represent a high level of plant evolution. To complete the peat-forming process, it is necessary to have coverage of the accumulating plant debris by stagnant water to prevent its oxidation and destruction. The floras that produce peat deposits are generally rich coastal type. The efficiency of peat-forming processes is relatively low, less than 10% of plant production is accumulated as peat. The large part is decomposed either during peat formation or after burial[13].

Besides the evolutionary state of plants, the climate and the tectonic conditions of the area are of primary importance in peat formation[27]. With increasing temperature and humidity, plant growth increases, resulting in amounting production of plant biomass. Tectonic events, such as the formation of depressions, graben structures or otherwise subsiding areas, (e.g. Nile Delta), are favorable for the formation of peat. For accumulation and preservation of thick deposits of peat, equilibrium between the accumulation rate of organic matter and subsidence has to be maintained over long periods of time.

### 2.3 Peat in the Eastern Nile Delta

The peat in the Eastern Nile Delta has been accumulated in Bilqas Formation in a fresh water marsh-swamp complex that occupied the Nile Delta during the standstill of the Holocene sea at 3690±140 years B.C. on its way to the present level[14]. It is of dark brown to black, non-compacted granular and have a moderate $H_2S$ order especially in the northern part. According to ASTM[3], the moisture content ranges from 20 to 35% while the ash content ranges from 37 to 48% and the organic carbon content ranges from 52 to 63%.

The depth of peat in eastern Nile Delta ranges between 13 m below the ground surface at the south of Mansoura; (study area) and 5 m at the north near Mediterranean. The maximum thickness of peat (3 m) is recorded also around Mansoura city and decreased gradually until it disappears in a configuration parallel to Damietta branch of the Nile River, (**Fig. 1**). In the northwestern part, peat is developed into two layers with average thickness of one meter at 5 and 8 m respectively separated by a silty sand layer[2)].

## 3. Geophysical methods

Surface geophysical methods vary widely in terms of the parameters they measure, including physical and chemical parameters. In most cases, measurements will be made on a station by station basis, along profile lines. However, some methods can provide continuous measurements along a profile line, which is called tomography[8)]. These continuous measurements provide high lateral resolution for mapping lateral changes in subsurface conditions. In this study we have conducted the DC resistivity tomography, induced polarization, self potential and time domain electromagnetic surveys.

### 3.1 DC resistivity/ IP methods

The use of electrical resistivity measurements called as an electrical resistivity tomography has been a favorite tool of geophysicists because of the wide range of resistivity values found in nature which represents a greater dynamic range than the other methods. Additionally, the advent of fast computing technologies permitted a broad use of the electrical resistivity tomography for environmental purposes[8,17,22,23)]. In electrical resistivity tomography measurements, the current is introduced into the ground through one pair of electrodes. A second pair of electrodes is then used to measure the voltage pattern on the surface resulting from the current flow pattern of the first set of electrodes. If multiple electrodes are used and the data are recorded automatically, the surveyed area can be searched more efficiently and various depths can be examined at the same time.

Simultaneously the time-domain Induced Polarization (IP) is measured with the resistivity data using same (dipole-dipole) array of electrodes configuration. The voltage between electrodes is measured as a decay function with time after the current has been switched off or as the current is switched on. The technique has found most use in the search for mineral deposits but has had some limited success in groundwater applications[9,10)].

In this work, resistivity and IP data were acquired along two profiles namely, LINE-1, and LINE-2 (**Fig. 2**), using the electrical resistivity method with dipole-dipole array of a maximum electrode spacing 8 m. The data collection was performed using the SYSCAL-R2 resistivity meter of IRIS Company[15)]. Usually, the apparent resistivity section produces a pseudo image of the subsurface resistivity. Hence, inversion of the field data is the standard procedure to obtain an estimate of the true resistivity distribution. A fast numerical approach is then used to optimize an initial model constructed directly from the observed apparent resistivity values[18)]. A finite difference or finite element method is usually used to calculate the 2-D forward response of the model. By the subsequent iterations, the model is updated until an acceptable fitting between the observed and model section is achieved. **Figure 3** illustrates the apparent and inverted resistivity cross sections along the LINE-1, while **Fig. 4** shows the apparent and inverted chargeability cross sections along the same profile. The RMS errors are fairly good of 11.8% and 7.4% for resistivity and chargeability sections respectively. Both of the sections consist of 382 data points.

### 3.2 Time Domain Electromagnetic (TDEM) method

Electromagnetic techniques have been extensively developed and adapted over the last

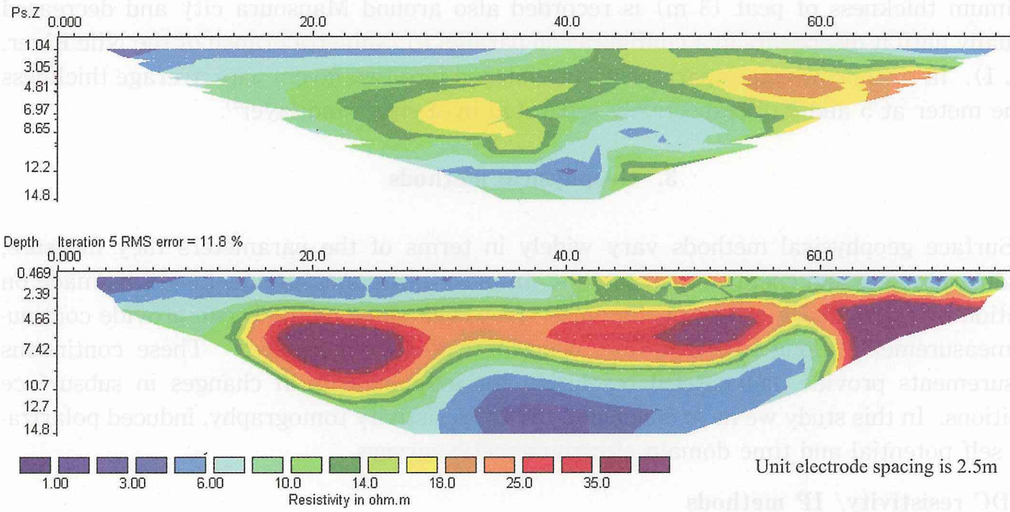


**Fig. 3** Dipole-dipole resistivity tomography sections along Line-1; (up) measured apparent resistivity, and (down) inverted resistivity section.

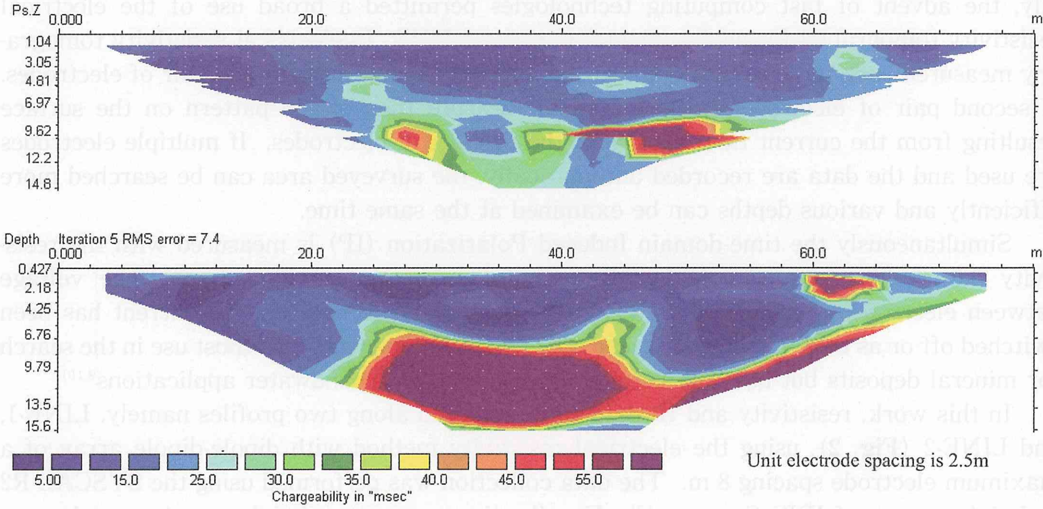
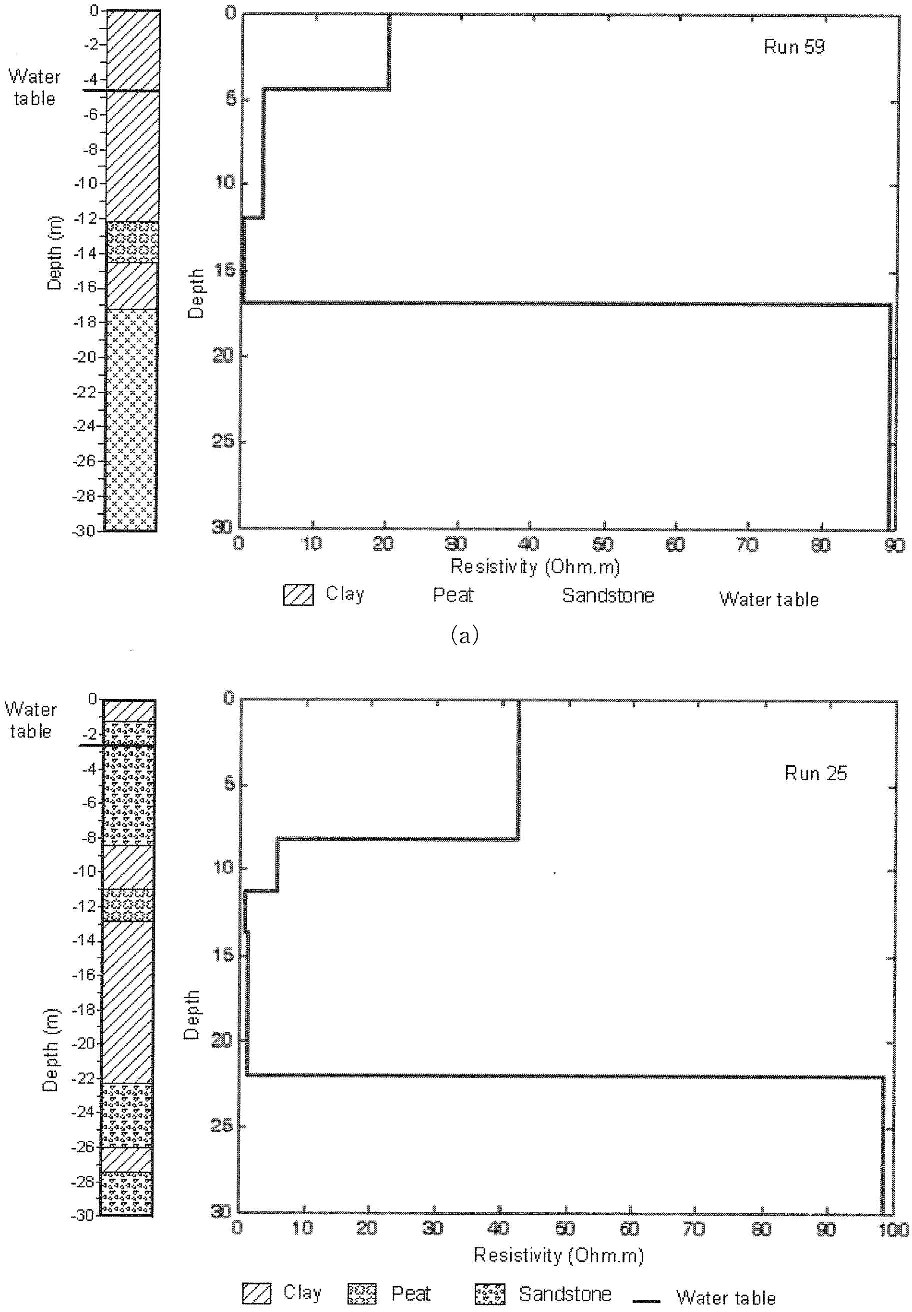


**Fig. 4** Dipole-dipole chargeability sections along Line-1; (up) measured apparent chargeability, and (down) inverted chargeability section.

few years to map lateral and vertical conductivity changes of the shallow subsurface[11,19,20]. While the final output is similar to that from electrical techniques, several advantages result in an increased resolution and more cost-effective application. Time domain electromagnetic technique has been applied in this study to measure the electrical conductivity (or resistivity) of the subsurface succession by inducing pulsating currents in the ground via a transmitter coil. After abruptly terminating the current, a receiver coil measures the decaying of electromagnetic field over a number of fixed times. The manner in which the electromagnetic field decays provides information on subsurface resistivity variations. Survey depths for TDEM are varying from 5 m to in excess of 100s of meters depending on the size of coils. However, the technique does not give high resolution from the surface to depth of 5 m. The method is extensively discussed by many authors[16,20,21]. Many regional case histories are now available to demonstrate the utility of TDEM[11,21].

Using the SIROTEM III acquisition system[6], suite of numbers of TDEM measurements were made at different stations along the measured 2-D resistivity/IP and SP profiles (**Fig. 2**). A simple coincident loop configuration was employed[11] with side length of 25 m and



(a)

(b)

**Fig. 5** Correlation between the available lithological logs and the measured TDEM stations at the two studied sites, a) site 59 and borehole No.1. b) site 25 and borehole No.2.

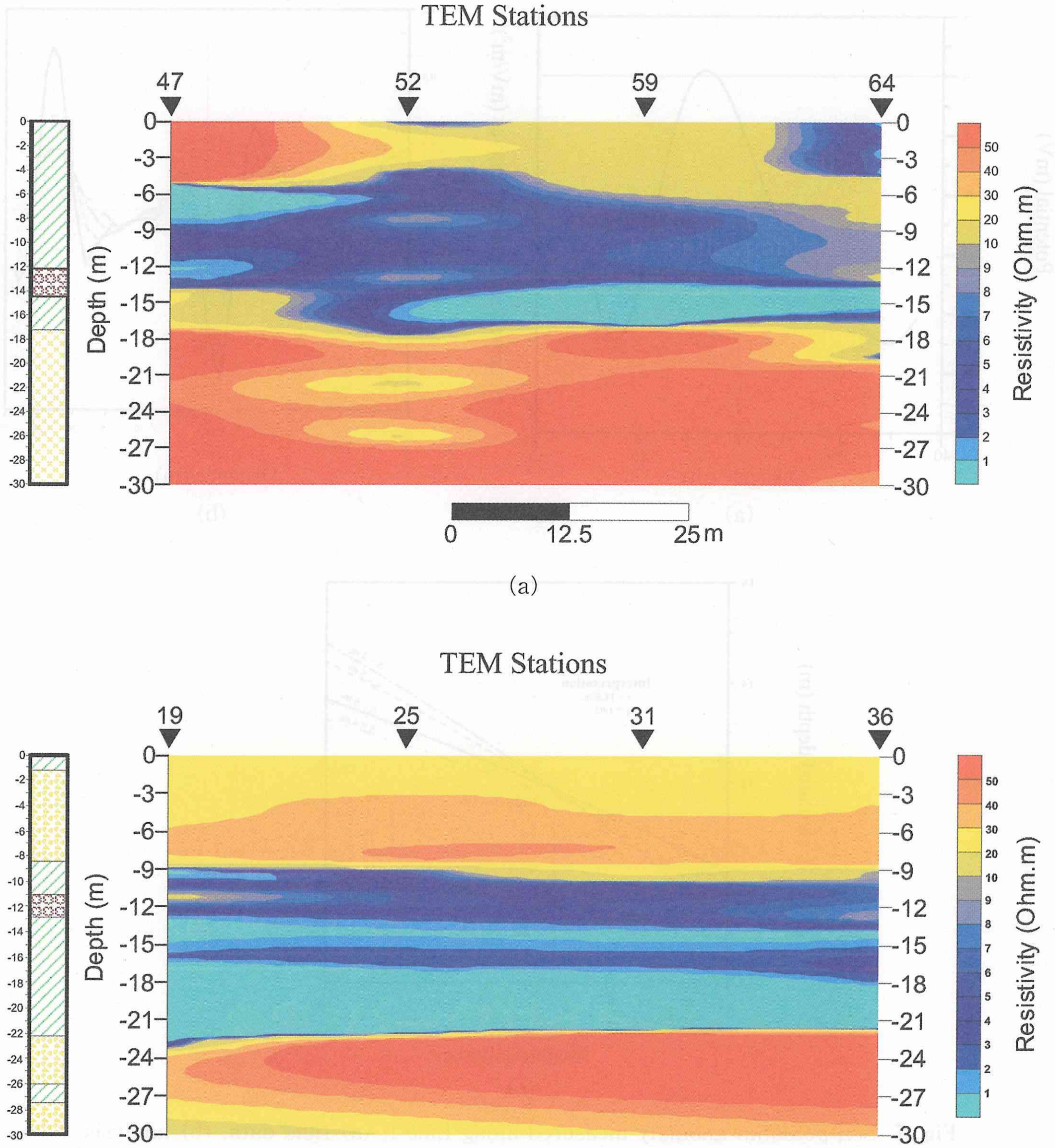
high-resolution recording mode.

Typical examples of the 1-D resistivity model obtained by inverting the TDEM data using TEMIX XL 4,[28] have been displayed with geological column, (**Fig. 5**). In general, the derived resistivity model is consistent with the major lithological contacts confirmed by borings of the boreholes (**Fig. 5**). Due to the relatively late times of the first TDEM recordings, it is impossible to derive information about the uppermost 5 meters and will appear in the derived model as one unit. In the correlation between the borehole No.1 and the resulted final model of station 59 (**Fig. 5 (a)**), the water table appears at a depth 4.3 m and separates the first clay layer to unsaturated zone and saturated zone. Those two zones have a good indication in the resulted resistivity model as the resistivity values decreased from 22 ohm-m to 3 ohm-m. Then the resistivity values are decreased again as a good indication for the presence of the peat and its underlain clay layer. The resistivity values increase again to 89 ohm.m as a good response for the presence of the sand layer which appears at a depth 17.2 m. In the correlation between borehole No.2 and the resulted resistivity model of station 25 (**Fig. 5 (b)**), the first layer has a relatively high resistivity value reached to 42.5 ohm-m and extends to a depth of 8.2 m. The very shallow water table (at a depth 2.7 m) cannot be resolved due to the limited resolving power of the TDEM method at this very shallow depth. The second layer is the very low resistivity and extends to a depth about 22 m. This depth is matching to the occurrence of the clay layer. The resistivity values inside this zone can hardly resolve the presence of the peat layer at depths from 11.0 m to 13 m that characterizing by the very low resistivity (about 1 ohm-m). The resistivity values increase again to 98.5 ohm-m as the deep sand layer appears again at a depth beyond 22 m. Based on the above correlation, the general number of layers and the correlated depths has been considered as flexible constraints in the inversions of the rest of the TDEM data along the two profiles, Lines 1 and 2 (**Fig. 6**).

### 3.3 Self Potential (SP) method

Spontaneous polarization or self potential (SP) method uses naturally occurring ground potentials from mineral bodies, geochemical reactions, and groundwater movement. The technique has been used in exploration for mineral deposits and successful applications have been seen for groundwater exploration as well as for engineering applications[7]. The method has also been used recently to investigate the leakage of systems such as landfill sites and natural dams[4,5].

The SP profiles have been measured along the two survey lines (**Fig. 2**) with electrode spacing of 5 meters. Using the SYSCAL-R2 with two non polarized porous pot electrodes, one at the infinity and the second moved along the profile, the data were measured. **Figure 7 (a)** displays the SP anomaly curve a long the Line-1. The field data have been processed and interpreted using the techniques proposed by Abdel Rahman et al.[1]. The separation of SP data using different derivative methods and four successive gradient windows (s=2, 3, 4 and 5) is displayed in **Fig. 7 (b)**, while **Fig. 7 (c)** display the relation of depth (z) as a function of shape factor (q) for the same windows.



(a)

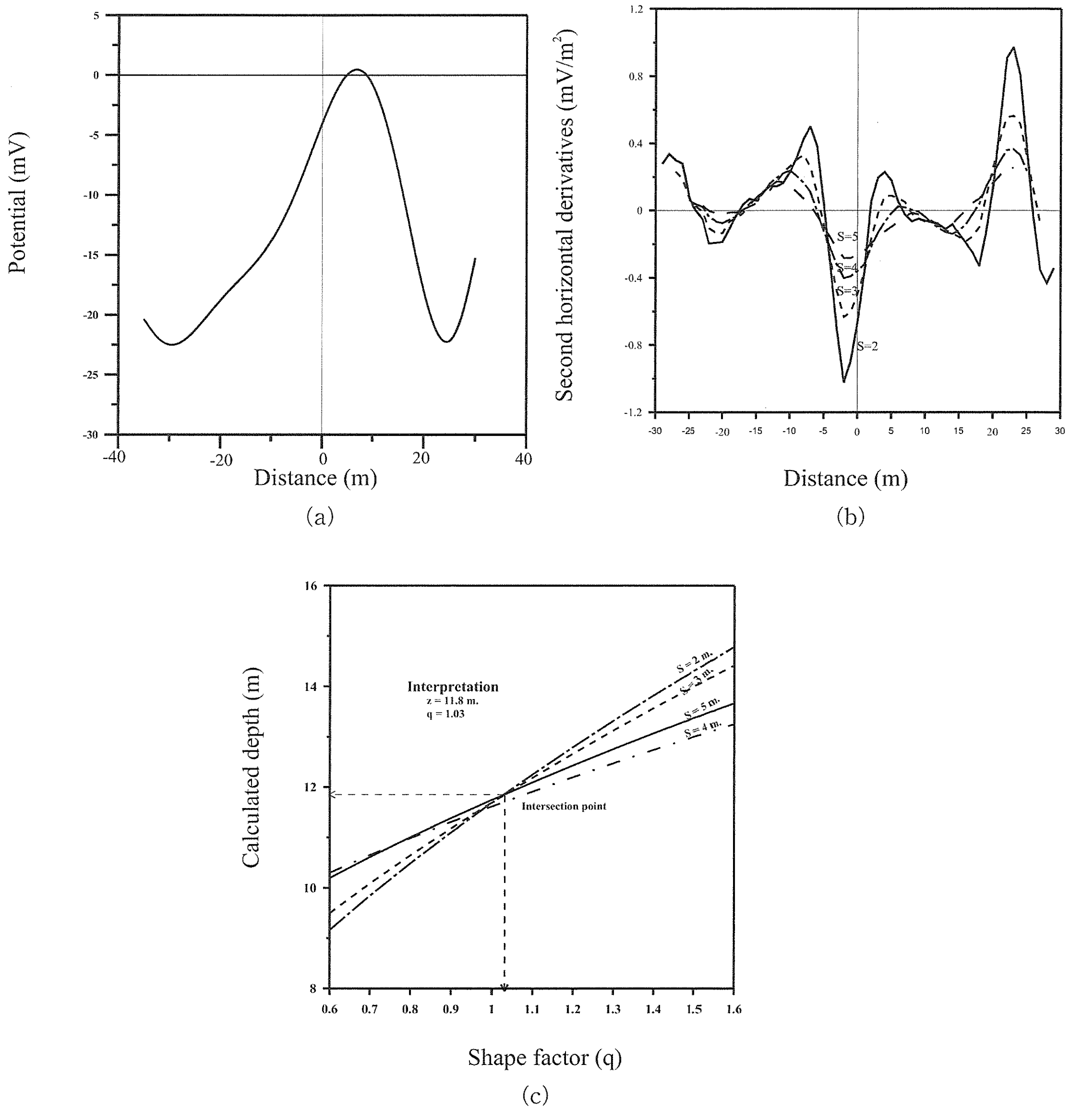
(b)

**Fig. 6** High-resolution resistivity profiles based on a TDEM data and its comparisons with lithological data: a) Line-1 and borehole No.1, b) Line-2 and borehole No.2.

## 4. Discussion

Integrated shallow geophysical surveys using Resistivity tomography, IP, TDEM and SP were conducted to investigate the credibility of the used geophysical techniques in detecting a peat layer at Mansoura area, Nile Delta, Egypt.

The resistivity tomography profiles (e.g. **Fig. 3**) show that the studied cross section is horizontally stratified which reflects the stable depositional environment in the Nile Delta area. Geologically, the first geoelectrical zone is representing the surface agricultural soil



(a) (b)

(c)

**Fig. 7** Self-potential anomaly measured along Line-1; (a) field data, (b) analysis for s= 2, 3, 4 and 5 using the second-derivative method and (c) family of window curves of z as a function of q using the second-derivative method.

layer which has a relatively low resistivity values, normally affected by the surface activities and the plants roots. This zone is followed by a moderate resistivity layer which represents the Holocene clay and silt layer. This layer is saturated by the groundwater and extends from 1 to 10 meter depth. While the third zone can not be differentiated by resistivity tomography, it is clearly characterized by high chargeability zone using IP data (**Fig. 4**). Depending on the borehole data nearby the surveyed site, constrains was estimated for solving the peat layer boundary. Basically the high chargeability can differentiate the zone into two lithological units of almost same resistivity which are peat and clay layers.

Same considerations had been taken as a first-order of the ambiguity reduction of inverting 1-D TDEM data. Comparing cross-section of the Line-1 with resulted TDEM model and the geological log in **Fig. 5** indicates that the section consists of four different geoelectrical layers. The first layer extends to a depth about 7 m and represents the aeration zone of the clay layer. The second layer is the saturated clay zone and is extending to a depth about 17 m. At depths from 13 to 16 m., the resistivity shows very low values which is correlating to the peat layer. The fourth layer which corresponds to the sand layer is considered as the shallow Pleistocene aquifer in the Nile Delta.

The cross section of Line-2 shows different lithological succession from the Line-1; although they are less than 1 km apart. The first layer represents the sand layer and extends to depth of about 9 m. The second layer represents the clay layer and extends to a depth of about 23 m. The peat layer appears at depths about 13 to 15 m and characterized by very low resistivity values. The fourth layer is the sand formation, which considers to be the shallow sand aquifer at the Nile Delta.

The results of SP data processing show that the regional anomaly along the profiles can be represented by a first-order polynomial. Also the shape factor and the depth obtained are 1.03 and 11.8 m respectively. This suggests that the body is a horizontal cylinder buried at a depth of 11.8 m, which highly correlates the lithological data available in the boreholes.

## 5. Conclusion

Borehole data in Nile delta shows existence of peat layer with considerable thickness. This peat layer is considered as one of the hazardous factors in the area, due to its characteristics of instability for supporting any kind of structure. This paper presents a case study to illustrate the creditability of surface geophysical surveys to detect peat layer at shallow depths in Mansoura city, where the maximum thickness of peat layer is recorded. A suit of shallow geoelectrical methods were used to demonstrate an integrated approach to detect the peat layer of maximum 3 meters thickness and a depth up to 13 m. Two resistivity /IP profiles along with SP and TDEM surveys have been conducted nearby two boring sites. An integrated interpretation of the data sets was done to determine the depth and thickness of the peat layer. Additionally, the borehole information was used to constrain the interpretation of the geophysical data. The lithological column of the 2 boreholes (**Fig. 5**) shows that in a distance less than 1 km, the lithology underlying peat varies from clay to sand and both of them is saturated with groundwater. Such lithological variation may be due to the several fluctuations in the Holocene sea level. The variations in the lithological sequence over and under the peat layer in the selected test sites add more interest to the interpretation of the geophysical methods used in this study. As a conclusion, the integrated geophysical survey could be successfully depicted depth and thickness of the peat layer in the study area. As a recommendation, further geophysical survey to delineate the extensions of peat layer is proposed to eliminate its risk affecting the infra structure in the Nile Delta area.

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