STUDY OF THE EFFECT OF INDUSTRIAL POOLS ON GROUNDWATER OCCURRENCES USING GEOELECTRICAL AND GEOCHEMICAL TECHNIQUES IN EL TEBEEN AREA – EGYPT

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دراسة تاثير البرك الصناعية على تواجدات المياه الجوفية باستخدام التقنيات
الجيوكهربية والجيوكيميائية بمنطقة التبين – مصر

الخلاصة: تتميز منطقة التبين بالعديد من الأنشطة الصناعية التى تنتج نفايات سائلة ضخمة. ويتم التخلص من هذه النفايات السائلة فى بحيرات محفورة بالقرب من نهر النيل أو تنقل إلى أماكن خاصة بالهضبة القريبة. وتمثل هذه المقالب السائلة مصادر تلوث للمياه الجوفية من خلال عمليات الترشيح والتسرب فى الطبقات المنفذة التى تعلو الخزان الجوفى الضحل. ويهدف هذا العمل إلى دراسة تأثير مكبات الصرف السائلة على المياه الجوفية ومياه النيل باستخدام تكامل التقنيات الجيوكهربية والجيوكيميائية. تم استخدام التقنيات الجيوكهربية مثل الجسات الكهربية الرأسية والمقاومة النوعية المقطعية والتى تشمل كلا من البروفيلات المقطعية ثنائية الأبعاد وثلاثية الأبعاد لدراسة الطبقات تحت السطحية وتواجد المياه الجوفية وإذا كان هناك اتصال بين مكبات الصرف السائلة والخزان الجوفى الضحل بمنطقة الدراسة، بالإضافة إلى تحديد أفضل الأماكن لحفر آبار المراقبة. تم تجميع عينات المياه من مكبات الصرف والآبار وآبار المراقبة والمياه السطحية للتحاليل الهيدروكيميائية لتحديد مكونات مكبات الصرف وعلاقتها بالمياه الجوفية وأيضاً لتحديد المعاملات الهيدروكيميائية وكمية كل عنصر ملوث الذى له علاقة بالنشاط الصناعى.

تشير نتائج التفسيرات الجيوكهربية وحفر آبار المراقبة فى منطقة غمازة والمصانع إلى أن مكبات الصرف رقم ١و٢و٤ تم حفرها فى طبقات منفذة من الرمال والحصى ولذلك يوجد تسرب واضح من هذه المكبات إلى الخزان الجوفى الضحل. وبمقارنة قيم كل من rCa/rMg والحديد فى كل من عينات مكبات الصرف وآبار المراقبة بمنطقة غمازة وجد أنها تعكس اتصال تلك المكبات بالخزان الجوفى الضحل. وأيضاً وجود كلوريد الماغنسيوم والحديد فى عينات مكب الصرف رقم ٤ والمياه الجوفية بمنطقة المصانع يشير بقوة إلى الاتصال بينهما. ومن ناحية أخرى تشير نتائج التفسيرات الجيوكهربية وعمليات الحفر بالجزء الشرقى من منطقة المصانع إلى انه لا يوجد تسرب من مكب الصرف رقم ٣ إلى الخزان الجوفى الضحل حيث انه حفر فى طبقات من الطين الرملى والطين. وأيضاً الزيوت والشحوم الموجودة فى النفايات السائلة بهذا المكب تغطى سطحه الداخلى وتعمل طبقات الطين كحاجز طبيعى. وبناءاً على نتائج هذه الدراسة فانه يجب أن تحفر مكبات الصرف فى المناطق المرتفعة شرق منطقة المصانع وأيضاً يجب أن تصمم وتبنى هذه المكبات من مواد غير منفذة لتجنب الرشح. ويجب استخدام آبار المراقبة فى ملاحظة التغيرات الدورية فى نوعية المياه الجوفية.

ABSTRACT: *El Tebeen area is characterized by many industrial activities that produce huge liquid wastes. These liquid wastes are disposed in excavated leaks near the Nile River or transported to special disposal sites (pools) in the nearest table land. The liquid dumps may form sources for groundwater contamination through leaching and infiltration processes into permeable layers above the shallow aquifers. The aim of this work is studying the effect of these liquid disposal sites on the groundwater and the Nile using integrated geoelectrical and geochemical techniques. Geoelectrical techniques such as Vertical Electrical Sounding (VES) and Electrical Resistivity Tomography (ERT), including both two dimensional (2-D) and three dimensional (3-D) resistivity profiling, were used to study the subsurface layering, groundwater occurrence and if there is a contact between these liquid disposal sites and the shallow aquifers in the study area; and to locate the best sites to drill monitoring wells. Water samples from the disposal sites, wells, monitoring wells and surface water were collected for hydrochemical analyses to determine the content of these waste disposals and its relation with the groundwater and also to determine the hydrochemical parameters and the amount of each pollutant, especially that related to the industrial activities.*

The results of the geoelectrical interpretation and the drilling of monitoring wells in Ghamaza and factories areas reveal that the disposal sites 1, 2 and 4 are excavated in permeable layers composed of sand and gravels. Consequently, a clear seepage exists from these sites to the shallow aquifer. The comparable values of rCa/rMg and Fe of both the disposal sites and monitoring well samples in Ghamaza area reflect the connection between these sites and the shallow aquifer. Also, the presence of $MgCl_2$ and Fe in the samples from the disposal site 4 and the groundwater in factories area refers to the strong connection between them. On the other hand, the results of the geoelectrical

interpretation and the drilling process in the eastern part from the factories areas indicate that no seepage from the disposal site 3 to the adjacent shallow aquifer where it is excavated in sandy clay and clay beds. Also, the oil and grease which exist in the liquid wastes in this site are coating its inner surface and the clay layers act as a natural barrier. Based on the results of this study the disposal sites must be excavated in high lands farther to the east in the factories area and these sites must be designed and built from impermeable materials to avoid seepages. The changes in the groundwater quality must be observed gradually by using the monitoring wells.

INTRODUCTION

The area under investigation is situated in El Tebeen area which is located south Helwan city by 20 km., it is bounded by latitudes 29º 42' 30" and 29º 46' 30" N and longitudes 31º 17' and 31º 20' E.

The study area is characterized by many industrial activities that produce huge waste in the liquid form. These liquid wastes are dumped or disposed on the excavated leaks near the Nile River or transported to special disposal sites in the nearest table land at Ghamaza area. The liquid dumps may form sources for groundwater contamination through leaching and infiltration processes into permeable layers above the shallow aquifers .

The study area is divided into two localities, the first one located at Ghamaza area in the downstream portion of Wadi Al Hera. This locality has two disposal sites (pools), the western one (site 1) is used to collect the industrial water waste from Iron and Steel Factory through pipes. The eastern one (site 2) is used to collect the sanitary wastewater. The other locality is located at the factories area in the downstream portion of Wadi Grawy close to the Nile River. It has two disposal sites, the first one (site 3) is located at the Coke Factory to collect the industrial liquid waste. The second one (site 4) is located at the Iron and Steel Factory to collect the industrial waste water (Fig.1). These disposal sites contain high levels of contaminated minerals (Fe, Mn, Cd, Pb, Zn, Cu and No3) that led to the formation of a contaminant plume below the industrial liquid waste sites which seriously harms the environment, especially the groundwater quality and may cause danger domestic and agricultural water supplies.

So, the aim of this work is studying the effect of the industrial liquid disposal sites on the groundwater and Nile River by using integrated geoelectrical and geochemical techniques.

The area under investigation is characterized by moderate to low relief with general slope towards the west (Nile River). The geomorphological units in this area are the young alluvial plain, the old alluvial plain and the calcareous structural plateau as arranged from west to east (Said, 1962). The age of the outcropped sediments ranges from Quaternary to Eocene and can be classified as:

- Pleistocene deposits: which consist mainly of sand and gravels with clay interbedded, they form terraces of different elevations above the flood plain and conformably overlie the Pliocene deposits and form the main water bearing formation east the Nile River.
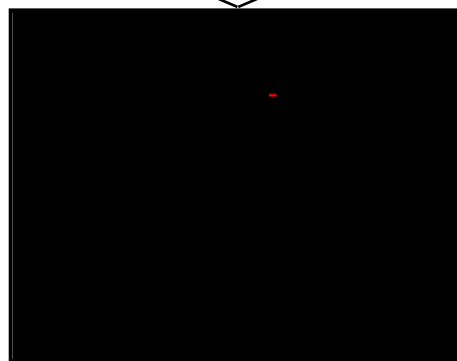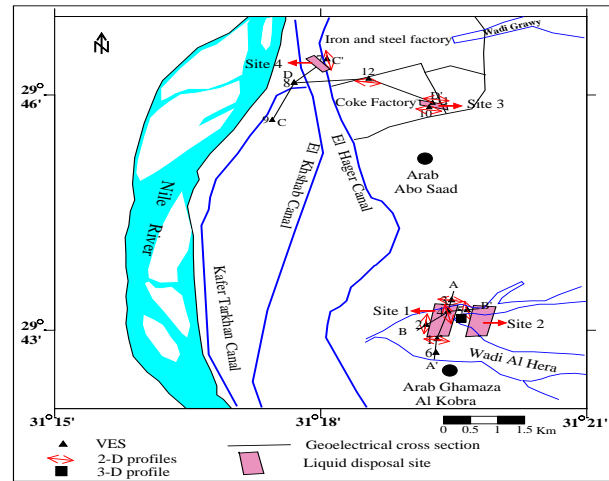
Fig 1: Location map of the study area.

- Plio-Pleistocene deposits: they consist mainly of conglomerates and have a wide distribution on the eastern side of the Nile Valley between the El Kuraimat and El Saff areas (Said, 1981).

- Pliocene deposits: which consist of a thick series of clay and thin, fine-grained sand and silt lamina which outcropping along the banks of the Nile Valley and many wadis.

- Eocene rocks: they are distributed in the eastern fringes of the study area and form high plain. These rocks are divided into two main units. The upper one is represented by Maadi Formation which consists of shallow marine shale and limestone with intercalations of marine sandstone. The Lower one is represented by Mokattam Formation that consists of limestone with chert and few nummulites.

Based on the hydrogeological studies that carried out in the study area and its vicinities, the Pleistocene sands and gravels are the main aquifer. The groundwater occurs under unconfined and semi-confined conditions (Abdel Shafy et al. 1986, El Sayed, 1993; Awad, 1999; El Sayed et al. 2004; Yousef, 2007; El Sheikh, 2008 & Al Temamy, 2011).

MATERIALS AND METHODS

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In the last decades, the assessment of groundwater contamination due to liquid disposal sites was proposed using different geophysical tools. Geophysical surveys can help investigators to characterize the site conditions and contamination (Zohdy et al., 1974). This subject was discussed in the works of Kelly, 1976; Campanella & Weemes, 1990; Bernardes et al., 1991; Campanella et al. 1993; Barker, 1996; Wang et al., 1998; Daly et al. 2002; Goldscheider, 2005; Vias et al., 2006; and Ravbar & Goldscheider, 2007.

Geophysical techniques are considered rapid, and less expensive and less time-consuming in the field of groundwater exploration, environmental and engineering problems. To achieve the target of this work, geoelectrical techniques such as Vertical Electrical Sounding (VES) and Electrical Resistivity Tomography (ERT), including both two dimensional resistivity profiling (2-D) and three dimensional resistivity profiling (3-D), were used to study subsurface layering, groundwater occurrence and if there is a contact between these liquid waste disposal sites and the shallow aquifers, and also to locate the best sites to drill monitoring wells in the study area.

Hydrochemical analyses were used to determine the content of these waste disposals and its relation with the groundwater and also to determine the amount of each pollutant especially that produced by the industrial activities.

Twelve Vertical Electrical Soundings were carried out in the area under consideration in two localities; each one has six VESes (Fig.2 & 3).
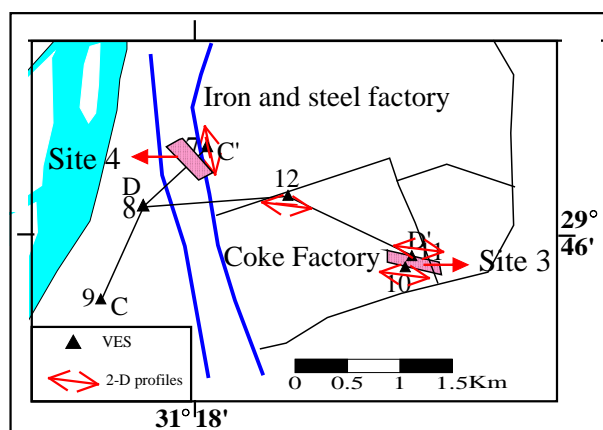
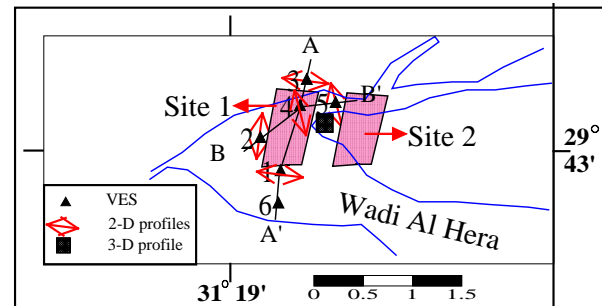**Fig. (2): Geoelectrical field measurements in Ghamaza area.**

Fig. (3): Geoelectrical field measurements in Factories area.

The first one is located in Ghamaza area and the other is located in the factories area close to the eastern side of the Nile River. These two sub areas are characterized by the presence of excavated leaks to dispose liquid wastes directly as in the industrial area or the industrial waste water is transported to it through pipes as in Ghamaza area. The field measurements of the VES were carried out with Terrameter SAS 1000 resistivity meter using Schlumberger array for electrodes arrangement. The maximum current electrode spacing (AB) was 600 m. Some of these VES stations were conducted adjacent to wells to use them as parametric measurements during interpretation. Field measurements in the form of AB/2 and apparent resistivity were plotted on bilogarithmic paper to obtain field curve at each VES station.

Nine 2-D resistivity profiles were carried out around the sides of these disposal sites to study the horizontal variations in resistivity with depth. Wenner array is an attractive choice for a survey carried out in a noisy area (due to its high signal strength) and also if good vertical resolution is required (Loke, 2001). The field measurements of these 2-D resistivity profiles were made by applying Wenner configuration using ABEM LUND imaging system (Terrameter SAS 1000, electrode selector ES 10-64, and multi conductor cables). Field survey technique was carried out with a system where the electrodes are arranged along a line with a constant spacing (a) between adjacent electrodes at the same datum points and increasing this space by a multiply factor (2, 3, 4, etc....) of a spacing to increase the penetration depth (Geotomo, 2004).

One 3-D resistivity imaging was carried out between the western and eastern disposal sites (1 & 2) in Ghamaza area to study the effect of these sites on the groundwater. Field measurements were done using Terrameter SAS 1000 resistivity meter and pole-pole array over a 6 by 6 grid with 4m grid spacing size and cross-diagonal measurement sequence technique.

Groundwater sampling is one of the most important tasks performed during a contamination investigation. Well sampling besides surface water and disposal sites sampling provide the hydrochemical and contaminant chemistry information for the problem under consideration. Twenty-one water samples were collected from the investigated areas, 6 samples representing Nile River and El-Khashab canal,

5 samples representing liquid disposal sites, and 10 samples representing wells (Fig. 4). Depth to water, EC, and pH were also conducted for water samples in situ. Chemical analyses were carried out for all the collected water samples to determine the concentrations of major and minor components in addition to the organic and bacteriological measurements according to the methods adopted by Rainwater and Thatcher, 1960; Fishman and Friedman, 1985; Greenberg, et al. 1985; Rowe, et al. 1995 and the American Society for Testing and Materials (ASTM), 2002.
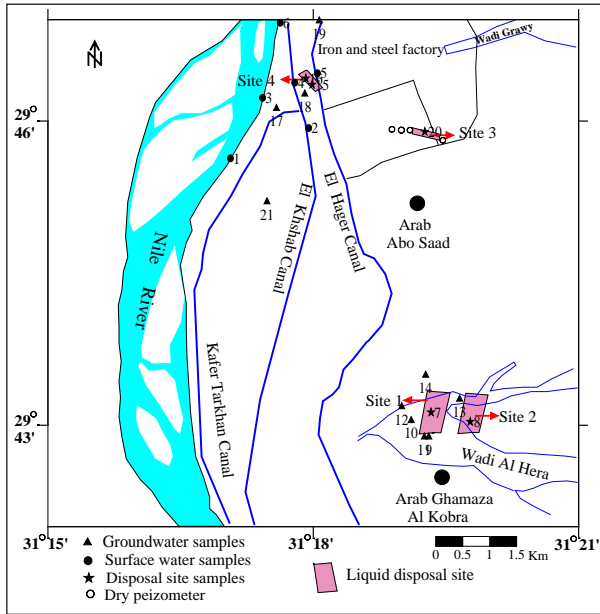

Fig. (4): Location map of the collected water samples.

RESULTS AND DISCUSSION

I: Geoelectrical techniques:

1- Vertical Electrical Sounding:

Quantitative interpretation of the field curves was made using the computer program RESIST (Vander Velpen, 1988) for non automatic iteration method in which the field data are compared with data calculated for an assumed earth layer model. This assumed model is based on all available information obtained primary from wells, geological and hydrogeological settings.

Quantitative interpreted data of each VES station was represented in terms of thicknesses and resistivities which were correlated with the actual data obtained from the adjacent water points. The interpreted data in Ghamaza and factories areas were used to construct 4-geoelectrical cross sections to identify the distribution of the resistivities, thicknesses and depth to water along the study area.

A: Ghamaza area:

The interpreted data in Ghamaza area reveals that the geoelectrical succession consists of six geoelectrical layers (Figs. 5 & 6), the following is the brief discription of these layers from top downwards:

Fig. (5): Geoelectrical cross section AA', Ghamaza area.
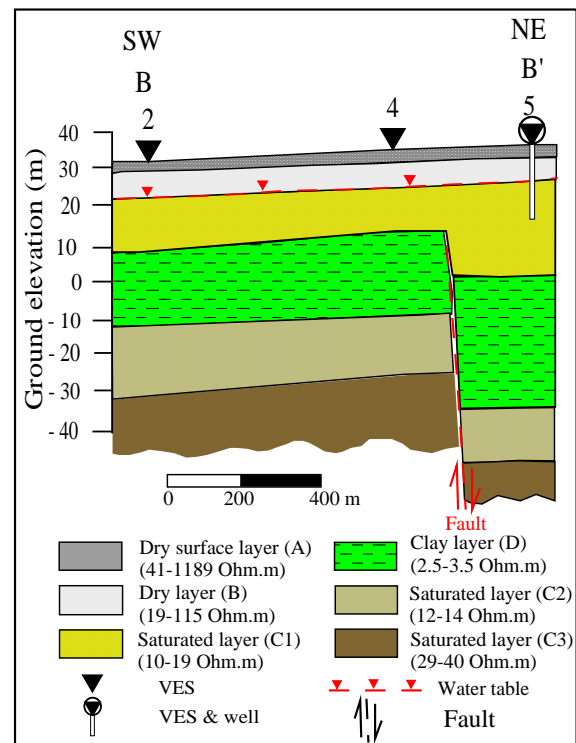
Fig. (6): Geoelectrical cross section BB', Ghamaza area.

1- Geoelectrical layer A:

This layer is considered as the dry surface layer. The resistivity of this layer varies widely from 41 Ohm.m at VES 4 to 1189 Ohm.m at VES 5. This wide variation in resistivity can be attributed to the variations in moisture content and fine materials of this layer. It consists of few thin layers that are composed of gravil and sand. The thickness of this layer ranges from 2.8 m at VES 6 to 3.6 m at VES 1.

2- Geoelectrical layer B:

This layer has a resistivity varing from 19 Ohm.m at VES 4 to 184 Ohm.m at VES 1 and its thickness ranges from 5.8 m at VES 3 to 7.9 m at VES 2. It consists of dry sand and gravel. The lower boundary of this layer can be correlated with the water table in the study area.

3- Geoelectrical layer C1:

This layer is defined as the water bearing layer; its resistivity ranges from 10 Ohm.m at VES 4 to 35 Ohm.m at VES 6. Its thickness varies from 11 m at VES 1 to 27 m at VES 5. It is composed of sand and gravel. Depth to this layer (depth to water) varies from 8.6 m at VES 3 to 10.8 at VES 2. The resistivity value of this layer at VES 1 (close to the southern part from the disposal site 1) is 29 Ohm.m which is less than its value (35 Ohm.m) at VES 6 (farther to the south) due to the direct seepage from this site to its surroundings. A normal fault exists between VES 4 and VES 5 with downthrow side towards the NE direction and cause the increase of the thickness of this layer at VES 5. The transportation of the pollutants from the shallow aquifer to the deep aquifer may be occurred through the fault plane.

4- Geoelectrical layer D:

This layer has a resistivity range from 2.5 Ohm.m at VES 5 to 4.2 Ohm.m at VES 3 and its thickness varies from 20.6 m at VES 6 to 38 m at VES 5. It is composed of clay beds.

5- Geoelectrical layer C2:

This layer is considered as a water bearing layer. Its resistivity ranges from 12 Ohm.m at VES 5 to 17 Ohm.m at VES 1 and its thickness varies from 14.3 m at VES 2 to 17.6 m at VES 1. It is composed of sand and clayey sand.

6- Geoelectrical layer C3:

This layer is defined as the lower water bearing layer. Its resistivity ranges from 29 Ohm.m at VES 4 to 41 Ohm.m at VES 3 and its lower boundry was not detected. It is composed of sand and gravel.

B: Factories area:

The interpreted data in factories area reveals that the geoelectrical succession consists of four geoelectrical layers (Figs. 7 & 8). The following is a brief discription of these layers from top downwards:
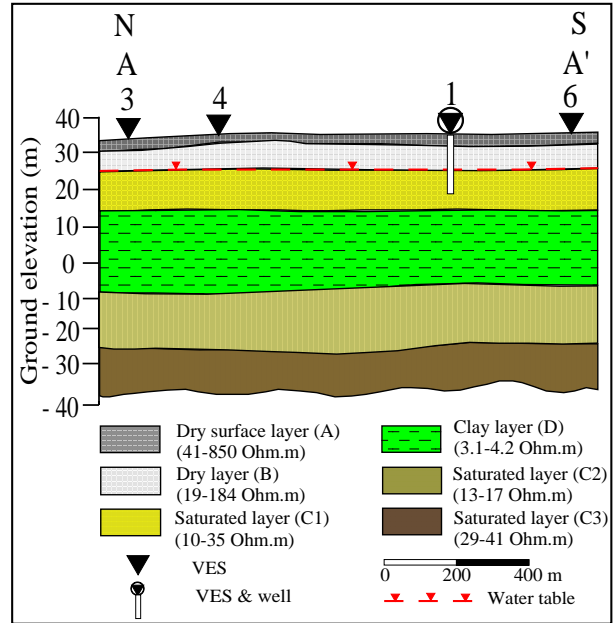
1- Geoelectrical layer A:

This layer is considered as the dry surface layer. The resistivity of this layer varies widely from 2.5 Ohm.m at VES 9 to 267 Ohm.m at VES 7. This wide variation in resistivity can be attributed to the variations in moisture content and fine materials of this layer which increases towards the Nile River at the west. It consists of a few thin layers that are composed of alluvial deposits (gravel, sand, silt and clay). The

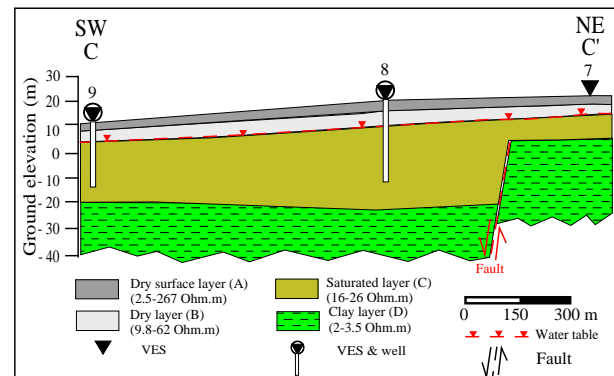thickness of this layer ranges from 2.4 m at VES 9 to 5.8 m at VES 11.

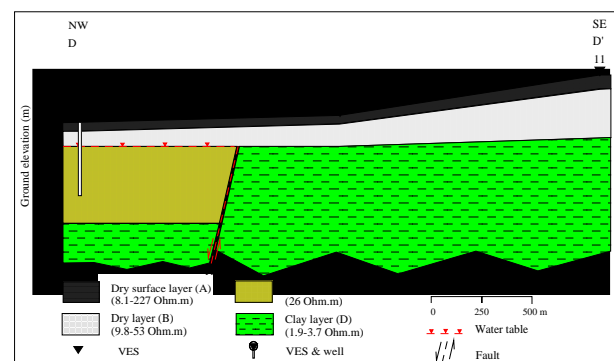**Fig. (7): Geoelectrical cross section CC',
Factories area**

**Fig. (8): Geoelectrical cross section DD',
Factories area.**

2- Geoelectrical layer B:

This layer corresponds to dry sandy clay and clay beds. Its resistivity varies from 9.8 Ohm.m at VES 8 to 62 Ohm.m at VES 7 and its thickness ranges from 3 m at VES 7 to 20.8 m at VES 11. Generally, the thicknesses of this layer decrease towards the west. The lower boundary of this layer can be correlated with the water table in the study area.

3- Geoelectrical layer C:

This layer represents the water bearing layer in the study area, it is composed of sandy clay and clayey sand. Its resistivity ranges from 16 Ohm.m at VES 7 to 26 Ohm.m at VES 8 and its thickness varies from 9.3 m at VES 7 to 32.2 m at VES 8. This layer is detected only in the western side from the study area near from the Nile River. Two normal faults are affecting this layer, the first one is located between VES 7 and VES 8 with a downthrow side towards SW direction, while the other fault occurred between VES 8 and VES 12 with a downthrow side towards the NW direction.

4- Geoelectrical layer D:

This layer is considered as the base of the succession at the depth of investigation. It is composed of clay beds and its resistivity ranges from 1.9 Ohm.m at VES 12 to 3.7 Ohm.m at VES 11. Its lower boundry is not determined.

2- Two dimensional resistivity profiling:

A- Ghamaza area:

RES2DINV program was used to the interpret 2-D resistivity measurements. This program automatically determines a two-dimensional (2-D) resistivity model for the subsurface for the data obtained from electrical imaging surveys (Griffiths and Barker, 1993). In Ghamaza area, five 2-D resistivity profiles were carried out with a total length of each profile 150 m. The smallest distance between the adjacent electrodes (a) was 5 m. The following is a brief description of these profiles (Fig. 9):
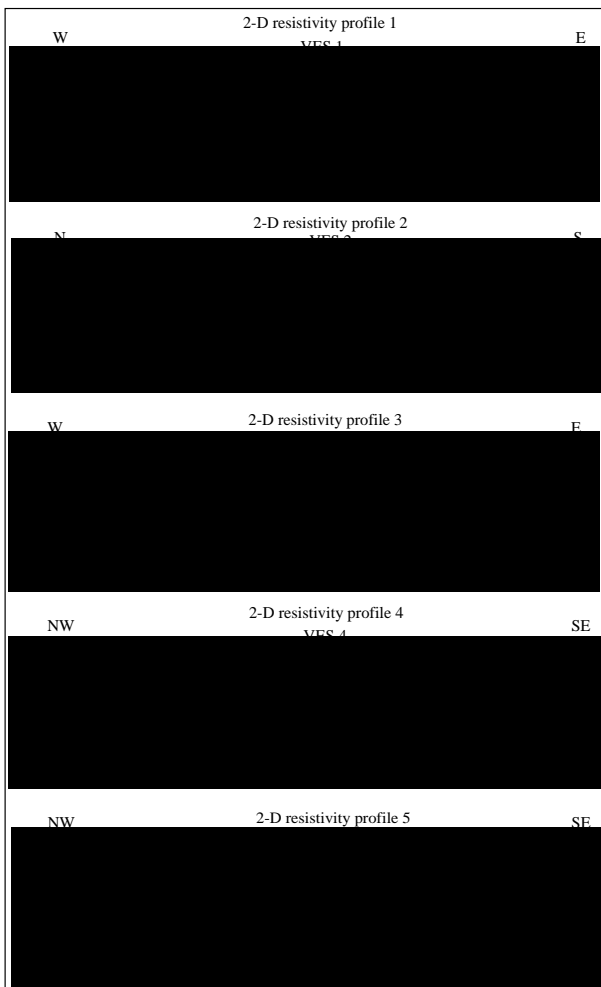

Fig. (9): 2-D resistivity models in Ghamaza area.

2-D resistivity profile 1:

This profile was carried out at the location of VES 1 and parallel to the southern side of the industrial disposal site 1. The interpreted model of this profile consists of three zones. The first zone represents dry zone with a resistivity from 65.9 Ohm.m to > 413 Ohm.m and its thickness 8 m. The second zone represents saturated zone with a resistivity range from < 65.9 Ohm.m to > 10.5 Ohm.m and its thickness about 12 m. The third zone is represented by a clay layer; it has resistivity less than 10.5 Ohm.m. It extends from depth 20 m to the end of this profile. The lower eastern

and western sides of this profile and composed of clay beds intercalated with sand beds with resistivity < 10.5 Ohm.m.

2-D resistivity profile 2:

This profile was carried out at the location of VES 2 and parallel to the western side of the industrial disposal site 1. The interpreted model of this profile consists of three zones. The first zone represents dry zone with resistivity range from > 43.5 Ohm.m to > 127 Ohm.m and its thickness is 10 m. The second zone represents saturated zone with resistivity ranging from < 43.5 Ohm.m to > 8.7 Ohm.m and its thickness is about 10 m. The third zone is composed of clay layers with resistivities less than 8.7 Ohm.m and it extends to the end of this profile.

2-D resistivity profile 3:

This profile was carried out at the location of VES 3 and parallel to the northern side of the industrial disposal site 1. The interpreted model of this profile consists of three zones. The first zone represents dry zone with a resistivity range from > 81.6 Ohm.m to > 293 Ohm.m and its thickness is 10 m. The second zone represents a saturated zone with resistivity range from < 81.6 Ohm.m to > 12 Ohm.m and its thickness 9 m. The lower zone of this profile is composed of clay beds and its resistivity < 12 Ohm.m.
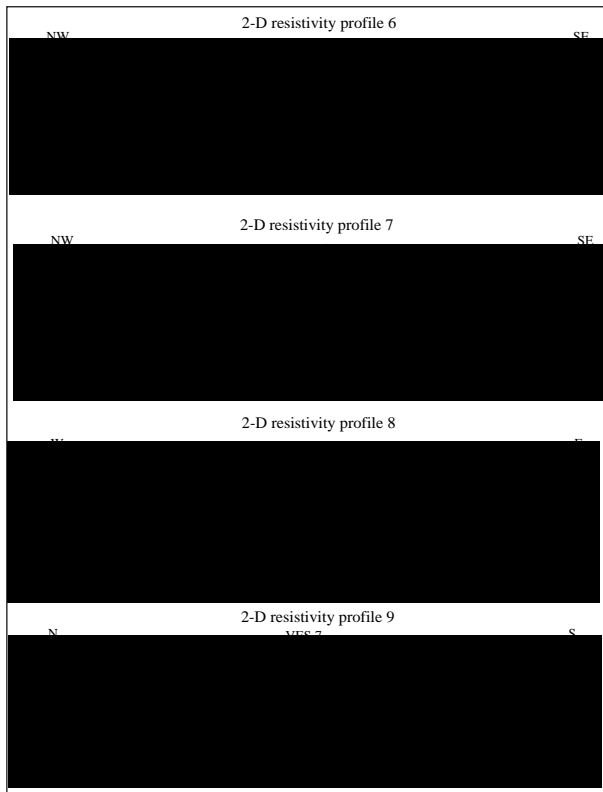
2-D resistivity profile 4:

This profile was carried out at the location of VES 4 near the northern part of the industrial disposal site 1. The interpreted model of this profile consists of three zones. The first zone represents dry zone with a resistivity range from > 85.9 Ohm.m to > 35.3 Ohm.m and its thickness 8 m. The upper surface of this layer is affected by seepages from the disposal site. The second zone represents a saturated zone with resistivity range from < 35.3 Ohm.m to > 10.8 Ohm.m and its thickness 9 m. The lower zone of this profile is composed of clay beds and its resistivity is < 10.8 Ohm.m.

2-D resistivity profile 5:

This profile was carried out at the location of VES 5 between the industrial disposal sites 1 and 2. The interpreted model of this profile consists of two zones. The first zone represents a dry zone with resistivity range from > 52.3 Ohm.m to > 201 Ohm.m and its thickness 9 m. The second zone represents a saturated zone with resistivity from < 52.3 Ohm.m to 19 Ohm.m and its thickness is not determined, which confirms the presence of a fault between VES 4 & VES 5 (Fig. 6).

B- Factories area:

In the factories area, four 2-D resistivity profiles were carried out with a total length varing from 600 m to 150 m. The smallest distance between the adjacent electrodes (a) was 10 & 5 m. The following is a brief description of these profiles (Fig. 10):

Fig. (10): 2-D resistivity models in factories area.

2-D resistivity profile 6:

This profile was carried out at the location of VES 10 and parallel to the northern side of the industrial disposal site 3. Its length is 300 m with the smallest distance between the adjacent electrodes 5m. The interpreted model of this profile consists of three zones. The first zone represents a dry surface layer with resistivity range from 24.6 Ohm.m to < 58 Ohm.m and its thickness 8 m. The second zone represents a dry layer with a resistivity range from 10.5 Ohm.m to < 24.6 Ohm.m with 18 m in thickness. The third zone is composed of clay beds with resistivity < 10.5 Ohm.m.

2-D resistivity profile 7:

This profile was carried out at the location of VES 11 and parallel to the southern side of the industrial disposal site 3. Its length is 300 m with the smallest distance between the adjacent electrodes 5 m. The interpreted model of this profile consists of three zones. The first zone represents dry surface layer with resistivity range from 48.3 Ohm.m to < 106 Ohm.m and its thickness 7 m. The second zone represents a dry layer with a resistivity range from 10.1 Ohm.m to < 48.3 Ohm.m with 20 m in thickness. The third zone is composed of clay beds with resistivity < 10.1 Ohm.m.

2-D resistivity profile 8:

This profile was carried out at the location of VES 12 and to the west from the industrial disposal site 3. Its length is 600 m with the smallest distance between the adjacent electrodes 10 m. The interpreted model of this profile consists of three zones. The first zone represents dry surface layer with a resistivity from > 9.92 Ohm.m

and its thickness 5 m. The second zone represents a dry layer with resistivity from 9.92 Ohm.m to 5.93 Ohm.m with 12 m in thickness. The third zone is composed of clay beds with resistivity < 5.93 Ohm.m.

2-D resistivity profile 9:

This profile was carried out at the location of VES 7 parallel to the eastern side of the industrial disposal site 4. Its length is 150 m with the smallest distance between the adjacent electrodes 5 m. The interpreted model of this profile consists of three zones. The first zone represents a dry zone with resistivity from 31 Ohm.m to < 231 Ohm.m and its thickness 5 m. The second zone represents a saturated sand with resistivity range from 11.4 Ohm.m to 31 Ohm.m with 12 m in thickness. The last zone is composed of clay beds with resistivity < 11.4 Ohm.m.

3- Three dimensional resistivity profiling:

RES3DINV program was used to interpret the data of 3-D resistivity imaging survey; it will automatically determine a three dimensional resistivity model for the subsurface. The 3-D resistivity model obtained from this survey indicates a good correlation with the interpreted data of the Vertical Electrical Sounding and 2-D resistivity profiling, where the depth to water is about 9.0 m. The southwestern side from this model is affected by the minerals contamination from the disposal site 1 which tends to increase the conductivity and hence decreases the resistivity at this side (Fig. 11).
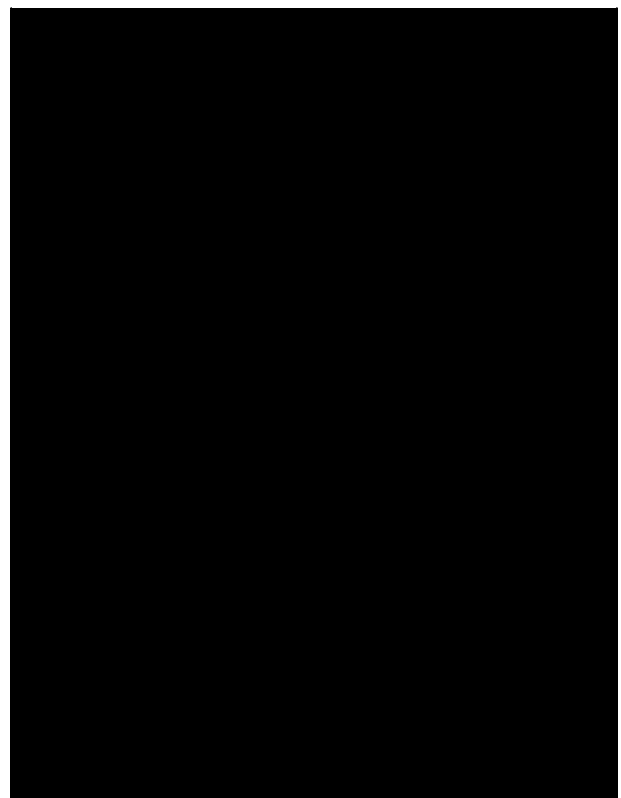
Fig. (11): 3-D resistivity model at Ghamaza area.

Based on the results of the Vertical Electrical Sounding and the 2-D resistivity profiling that are carried out in Ghamaza and factories areas many sites were selected to drill monitoring wells and test the presence of the groundwater. In Ghamaza area two sites were selected at the location of VES 1 (southern part from disposal site 1) and VES 5 (between the disposal sites 1 & 2 at the northern part). The total depth of each well was 15 m. All the sedimentary section varies from sand and gravel at the upper layer and fine sand at the lower layer. Depth to water was 9.5 m in the monitoring well at VES 5 and 7.5 m at the monitoring well at VES 1. These results agree with those obtained from the geoelectrical studies.

In the factories area at the disposal site 3, four test holes were drilled to detect any seepage from this disposal site to the sediments around it. The results of drilling indicate that the sedimentary section is dry to depth 15 m and is composed of sandy clay and clay intercalations which agree with the results of the geoelectricl studies. But, at the disposal site 4 one monitoring well was drilled at its western side with a depth of about 15 m. The sedimentary section is composed of coarse and fine sand, and depth to water was 3 m which is the same level of water in this disposal site.

II: Geochemical results

1- Hydrochemistry of Nile and El-Khashab canal waters:

- The pH values of the surface water samples range from 7.6 (sample 5) to 8.7 (sample 3) with an average value of about 8.18, reflecting a slightly alkaline water (table 1).

- Values of the total water salinity reflect fresh water category, where they range from 184 mg/l (sample 1) to 197 mg/l (sample 4) with an average content of about 190 mg/l.

- Values of rNa/rCl exceed unity, where they range from 1.21 (sample 5) to 1.51 (sample 1) with an average value of 1.36 reflecting fresh water category. Also, values of rCa/rMg exceed unity, where they vary from 1.01 (sample 4) to 1.26 (sample 5), reflecting the increase of calcium on the account of magnesium. On the other hand, the values of rSO$_4$/rCl are less than unity, where they range from 0.37 (sample 5) to 0.49 (sample 6).

- Ion dominance shows that, the chemical water type is HCO$_3$-Ca, reflecting fresh water category. This water type is proved by the hypothetical salts; NaCl, Na$_2$SO$_4$, NaHCO$_3$, Mg (HCO$_3$)$_2$, & Ca (HCO$_3$)), which contain three types of carbonate salts.

- Values of the minor components (Fe, Mn, Pb, Zn, Cu, Cd & NO$_3$) are recorded in table 2. Noteworthy, Fe concentration varies in Nile water according to the sample site, where it records the highest value in front of the factories area (2.41 mg/l, sample 4) and decreases gradually southwards (0.40 mg/l, sample 1) and northward (0.18 mg/l, sample 5), (Fig. 12). The

values of Mn, Pb and Zn reflect a slight pollution. On the other hand, the water is safe with respect to both Cu and NO$_3$.
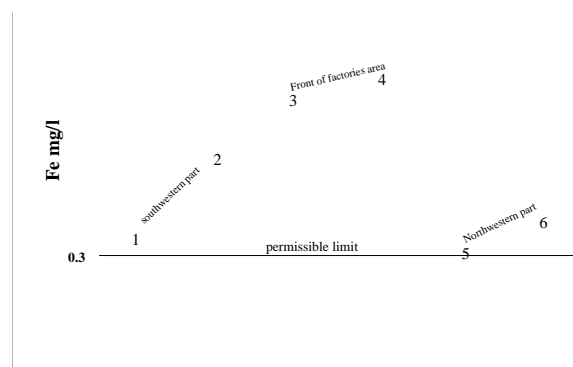

Fig. (12): Fe concentration in surface water samples

- Generally, values of chemical oxygen demand (COD) range from 18 to 1030 mg/l, exceeding the acceptable limit for drinking purpose. This reflects fertilizers misuse as well as the presence of municipal water.

- Bacteriological analyses showed that, the majority of samples are polluted by coliform bacteria with different degrees, which are more comparable with the total colony count. Also, Triple Sugar Iron reaction test (TSI) indicates that, the investigated water is polluted by Shigella (samples 2 & 3) and Klebsella (sample 6). This is mainly attributed to the direct discharge of sanitary wastewater (sewage) into surface water system in the investigated area. These types from bacteria can cause serious illness into the human beings.

2- Hydrochemistry of Ghamaza area:

- The pH values record wide variation at the disposal sites 1&2. They record 7.4 in the disposal site 2 (sample 8) and 9.5 in the disposal site 1(sample 7), reflecting alkaline character in the latter due to the discharge of industrial liquid waste on it (field observation). On the other hand, pH values of the groundwater vary slightly from 7.2 (sample 14) to 7.9 (sample 9) with an average of 7.6 reflecting neutral water type.

- Water salinity in the disposal sites records 491 mg/l (sample 7) and 2390 mg/l (sample 8). The high salinity can be attributed to the disposal of both sewage and agricultural drains into this site. The groundwater salinity varies from 1169 mg/l (sample 10) to 4021 mg/l (sample 14), reflecting fairly fresh to brackish water types. Such values of relative high salinity reflect the impact of leaching and dissolution processes of fluviomarine deposits on groundwater quality during the groundwater movement.

- rNa/rCl is recording 0.88 in the disposal site 1 (sample 7) and 1.27 in the disposal site 2 (sample 8). rCa/rMg records 2.72 (sample 7) and 1.93 (sample 8). The increase of Ca on the account of Mg is mainly attributed to the dissolution of calcareous deposits dominating the area as a result of breakdown of

limestone plateau to the east by the action of rainfall and flash floods. rSO_4/rCl records wide variation where it varies from 0.29 (sample 7) to 1.38 (sample 8) as a result of discharge of sewage into the latter site. On the other hand, the value of rNa/rCl is more-or-less unity in the groundwater samples proving the effect of Nile River and rainfall as recharging sources, in addition to the effect of some hydrochemical processes as cation exchange. rCa/rMg always exceeds the unity in all samples, where it ranges from 1.56 (sample 9) to 2.10 (sample 13), the increase of Ca on the account of Mg is strongly attributed to the calcareous deposits dominating the area as a result of breakdown of limestone plateau to the east by the action of rainfall and flash floods. rSO_4/rCl records low values, where it ranges from 0.28 (sample 14) to 0.62 (sample 13).

- Ion dominance in both the disposal sites and the groundwater samples shows that the chemical water type is Cl–Na, reflecting the advanced phase of water evolution. The disposal site 1 (sample 7) is characterized by $NaCl$, Na_2SO_4, $MgSO_4$, $Mg(HCO_3)_2$, and $Ca(HCO_3)_2$ while the disposal site 2 (sample 8) is characterized by $NaCl$, Na_2SO_4, $MgSO_4$, $CaSO_4$, and $Ca(HCO_3)_2$. The presence of $CaSO_4$ salt in sample 8 proves again the effect of agricultural drainage and sewage upon this site. On the other hand, two assemblages of hypothetical salts are recognized in the groundwater samples; $NaCl$, Na_2SO_4, $MgSO_4$, $CaSO_4$, and $Ca(HCO_3)_2$ & $NaCl$, $MgCl_2$, $MgSO_4$, $CaSO_4$, and $Ca(HCO_3)_2$. These salts reflect the important role of leaching, dissolution as well as cation exchange processes during groundwater movement.

- The study of minor and trace constituents reveals that, Fe records 1.06 mg/l in the disposal site 2 (sample 8) and 3.32 mg/l in the disposal site 1(sample 7) due to the discharge of liquid industrial waste into this site. On the other hand, Fe concentration in the groundwater samples is ranging between 0.32 mg/l due west (sample 12) and 3.12 mg/l due south (sample 11), (Fig. 13).
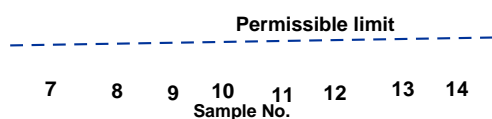
Permissible limit

| 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |

Sample No.

Fig. (13): Fe concentration in Ghamaza area

- Values of chemical oxygen demand (COD) in the majority of samples range from 120 to 386.4 mg/l, exceeding the acceptable limit for drinking purpose.

- The bacteriological analyses showed that, the investigated water is polluted by coliform that strongly comparable with the total colony count. Also, Triple Sugar Iron reaction test (TSI) indicates that, samples 9 & 10 are polluted by Shigella and samples 8, 11, 12 & 14 are polluted by Klebsella.

It is clear that, values of rCa/rMg for the disposal site1 (2.72 for sample 7) and the monitoring well (1.57 for sample 11) show the connection between both. This is strongly proved through the recorded values of Fe at the disposal site1 (3.32 for sample 7) and the monitoring well (3.12 for sample 11), which reflect seepage from the disposal site1 to the adjacent groundwater aquifer due south.

3- Hydrochemistry of factories area:

- pH values of the disposal site 4 range between 9.2 (sample 16) and 9.4 (sample 15) reflecting alkaline water. In the case of groundwater samples, pH values range from 6.20 (sample 18) to 7.80 (sample 19) showing natural water character.

- Water salinity of the disposal site samples varies from 332 mg/l (sample 15) to 765 mg/l (sample 16). The groundwater salinity varies between 420 mg/l (sample 19) and 895 mg/l (sample 17) showing fresh water category.

- The ratio of rNa/rCl in the disposal site samples ranges from 0.22 (sample 16) to 0.58 (sample 15) reflecting the role of ore-leaching process, which in turn increase Cl on the account of Na. rCa/rMg record values more than unity, where it ranges from 1.31 (sample 15) to 1.50 (sample 16) showing the increase of Ca on the account of Mg due to dissolution of calcareous deposits dominating the area as a result of breakdown of limestone plateau to the east by the action of rainfall and flash floods. rSO_4/rCl varies from 0.27 (sample 15) to 0.32 (sample 16). On the other hand, in the investigated groundwater, rNa/rCl ranges from 0.89 (sample 17) to 1.51 (sample 19) reflecting cation exchange process. In turn increase of Na on the account of Ca, rCa/rMg records values less than unity, where it ranges from 0.81 (sample 17) to 0.93 (sample 18). rSO_4/rCl varies widely, where it ranges from 0.14 (sample 18) to 0.96 (sample 19) showing no effect for agricultural drainage or sewerage.

- The ion dominance in the disposal site samples reflects two categories; Cl-Ca & Cl–Na, reflecting final stage of water evolution, whereas in the investigated groundwater. The chemical type varies widely from HCO_3-Mg (sample 19) to Cl-Na (samples 17 & 18), (Figure 14).

- The major ion combination in the disposal site samples reveals the presence of $NaCl$, $MgCl_2$, $MgSO_4$, $CaSO_4$ and $Ca(HCO_3)_2$, showing the effect of discharge for waste water composed of cooling, ore-washing and gas-removal waters as mentioned before. In the investigated groundwater, three assemblages of hypothetical salts are recognized as follows:

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Table (1): The hydrochemical analyses data in Nile and El Khashab canal water samples (2010).

Sample No.	E.C	pH	TDS		Ca	Mg	Na	K	Cations	CO₃	HCO₃	SO₄	Cl	Anions
1	362	8.50	184.72	ppm	23.15	13.18	25.00	8.00		0.00	153.70	13.04	25.50	
				epm	1.16	1.08	1.09	0.20	3.53	0.00	2.52	0.27	0.72	3.51
				%	32.71	30.70	30.80	5.80	100.00	0.00	71.78	7.74	20.49	100.00
2	395	8.10	196.09	ppm	26.10	15.21	24.00	8.00		0.00	162.00	16.28	25.50	
				epm	1.30	1.25	1.04	0.20	3.80	0.00	2.66	0.34	0.72	3.71
				%	34.26	32.90	27.46	5.38	100.00	0.00	71.51	9.13	19.37	100.00
3	372	8.70	186.30	ppm	25.12	14.11	23.00	8.00		0.00	153.70	13.72	25.50	
				epm	1.25	1.16	1.00	0.20	3.62	0.00	2.52	0.29	0.72	3.52
				%	34.64	32.06	27.65	5.65	100.00	0.00	71.49	8.11	20.41	100.00
4	374	8.20	197.20	ppm	25.12	15.11	25.00	7.00		0.00	168.00	15.47	25.50	
				epm	1.25	1.24	1.09	0.18	3.76	0.00	2.75	0.32	0.72	3.79
				%	33.31	33.03	28.90	4.76	100.00	0.00	72.56	8.49	18.95	100.00
5	385	7.60	192.08	ppm	27.10	13.10	24.00	8.00		0.00	148.00	15.28	30.60	
				epm	1.35	1.08	1.04	0.20	3.68	0.00	2.43	0.32	0.86	3.61
				%	36.76	29.29	28.38	5.56	100.00	0.00	67.25	8.82	23.93	100.00
6	340	8.00	192.08	ppm	25.12	14.20	22.00	7.00		0.00	147.70	16.81	25.50	
				epm	1.25	1.17	0.96	0.18	3.56	0.00	2.42	0.35	0.72	3.49
				%	35.24	32.83	26.90	5.03	100.00	0.00	69.37	10.03	20.61	100.00

E.C (microsiemns/cm)   TDS (mg/l).

Table (2): Most important minor components in Nile and El Khashab canal water samples (2010).

Sample No.	Fe (mg/l)	Mn (mg/l)	Pb (mg/l)	Zn (mg/l)	Cu (mg/l)	Cd (mg/l)	NO₃ (mg/l)	Organic matter	Organic carbon	Chemical oxygen demand	Coliform count (MPN/100 ml)*	Total colony count *10² SPC/ml at 37 °C**
1	0.40	0.04	0.16	0.09	0.19	0.02	0	0.003	0.001	92	17	300
2	1.35	0.27	0.20	0.08	0.19	0.07	0	0.009	0.005	202.4	1800	320
3	2.22	0.04	0.80	0.01	0.15	0.03	0	0.003	0.001	1030.4	1800	340
4	2.41	0.05	0.34	0.11	0.15	0.08	0	0	0	18.4	-	106
5	0.18	0.17	0.10	0.18	0.11	0.02	0	0	0	487.6	-	61
6	0.60	0.02	0.14	0.05	0.19	0.12	0	0	0	92	70	136
Permissible limit for drinking	0.3	0.05	0.01	5	1.3	0.005	44	-	-	10	<9	<50
Permissible limit for irrigation	5.0	0.20	5.0	2.0	0.20	0.01	-	-	-	-	-	-

Table (3): The hydrochemical analyses data in Ghamaza area (2010):

Sample No.	pH	E.C	TDS	Units	Ca	Mg	Na	K	CO₃	HCO₃	SO₄	Cl
**Disposal sites 1 & 2**												
7	9.50	830	490.90	Ppm	58.80	13.10	73.00	56.00	13.30	198.00	50.20	127.5
				Epm	2.93	1.08	3.18	1.43	0.44	3.25	1.05	3.60
				%	34.04	12.50	36.84	16.62	5.32	38.96	12.55	43.17
8	7.40	3880	2390.09	Ppm	250.00	78.59	440.00	19.00	0.00	134.50	999.75	535.5
				Epm	12.48	6.46	19.14	0.49	0.00	2.20	20.81	15.10
				%	32.35	16.76	49.63	1.26	0.00	5.78	54.60	39.61
**Groundwater**												
9	7.90	4930	3124.49	Ppm	208.12	80.97	800.00	9.00	15.00	106.80	758.00	1200
				Epm	10.39	6.66	34.80	0.23	0.50	1.75	15.78	33.84
				%	19.94	12.79	66.83	0.44	0.96	3.37	30.42	65.24
10	7.50	1810	1168.95	Ppm	107.80	32.15	250.00	32.00	0.00	194.00	280.00	370
				Epm	5.38	2.64	10.88	0.82	0.00	3.18	5.83	10.43
				%	27.28	13.41	55.16	4.15	0.00	16.35	29.98	53.66
11*	7.80	3960	2362	Ppm	210.12	80.97	495	18.83	-	159.60	577.70	900
				Epm	10.84	6.65	21.52	0.48	-	2.62	12.02	25.38
				%	26.78	16.99	54.99	1.22	-	6.54	30.03	63.41
12	7.50	2180	1381.75	Ppm	117.60	38.10	330.00	12.00	4.05	240.00	320.00	440
				Epm	5.87	3.13	14.36	0.31	0.13	3.93	6.66	12.41
				%	24.80	13.24	60.66	1.30	0.58	17.00	28.79	53.62
13*	7.70	4390	2609	Ppm	288.12	86.92	510	4.49	-	225	739.30	868.6
				Epm	14.38	7.15	22.17	0.11	-	3.68	15.39	24.49
				%	32.82	16.32	50.60	0.25	-	8.44	35.53	56.22
14	7.20	6670	4020.65	Ppm	300.00	98.20	1000.00	21.00	0.00	140.90	695.00	1836
				Epm	14.97	8.08	43.50	0.54	0.00	2.31	14.47	51.78
				%	22.32	12.10	64.84	0.80	0.00	3.37	21.11	75.52

*Monitoring wells

Table (4): Heavy metals and minor components in Ghamaza area (2010)

Sample No.	Fe	Mn	Cd	Pb	Zn	Cu	NO₃	O.M	O.C	COD	Coliform count	Total colony
**Disposal sites 1 & 2**												
7	3.32	0.03	0.08	0.64	0.20	0.11	5.4	0.009	0.005	276	1800	480
8	1.06	0.10	0.11	0.09	0.49	0.12	6.8	0	0	165.6	1800	425
**Groundwater**												
9	2.82	0.16	0.04	0.13	0.09	0.11	35.5	0	0	120	1700	300
10	1.06	0.01	0.05	0.51	0.13	0.12	14.1	0	0	128.8	1800	316
11*	3.12	0.361	0.06	0.14	0.11	0.12	9.5	0	0	0	130	185
12	0.32	0.06	0.02	0.05	0.04	0.09	13.3	0	0	184	1800	372
13*	1.80	0.329	0.12	0.23	0.11	0.08	11.1	0	0	0	7	103
14	0.57	0.02	0.22	0.58	0.07	0.07	5.4	0	0	386.4	8	148
Permissible limit for drinking	0.3	0.05	0.01	5	1.3	0.005	44	-	-	-	<9	<50
Permissible limit for irrigation	5.0	0.20	5.0	2.0	0.20	0.01	-	-	-	-	-	-

* Monitoring well

NaCl, MgCl$_2$, MgSO$_4$, CaSO$_4$ and Ca (HCO$_3$)$_2$ (sample 17).

NaCl, MgCl$_2$, MgSO$_4$, Mg (HCO$_3$)$_2$ and Ca (HCO$_3$)$_2$ (sample 18).

NaCl, Na$_2$SO$_4$, MgSO$_4$, Mg (HCO$_3$)$_2$ and Ca (HCO$_3$)$_2$ (sample 19).

- Fe content in the disposal site samples ranges between 2.95 mg/l (sample 15) and 3.20 mg/l (sample 16). Such high values are due to direct discharge of ore-washing water into the disposal site. In the investigated groundwater samples, Fe concentration ranges from 0.42 mg/l to the north (sample 19) to 1.97 mg/l (sample 18) to the west of the disposal site (Fig. 14).
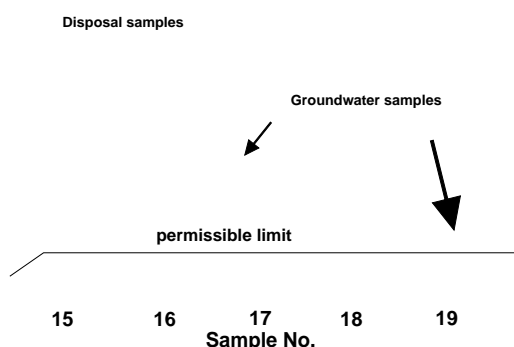

Fig. 14: Fe concentration in factories area.

- Values of chemical oxygen demand (COD) range from 156.4 to 579.6 mg/l, exceeding the acceptable limit for drinking.

- Bacteriological analyses indicated that, the investigated samples are slightly polluted by coliform, which are comparable with the total colony count. Also, Triple Sugar Iron Reaction test (TSI) indicates that, the water is polluted by Bacillus (samples 15 & 16) and Shigella (sample 17). Noteworthy, presence of MgCl$_2$ at the disposal site 4 (samples 15 & 16) and shallow groundwater (samples 17 & 18) refers to the strong connection between them. This is strongly proved through the values of Fe recorded at the disposal site (2.95 & 3.2 for samples 15 & 16) and the monitoring well (1.97 for sample 18).

On the other hand, geoelectrical results and drilling process in the eastern part of factories area indicated that no seepage from the disposal site3 (excavated in sandy clay and clay beds) to the adjacent shallow aquifer because the oil and grease exist in the liquid wastes in this site are coating its inner surface and also the clay layers are acting as a natural barrier.. This is chemically proved through the recorded values of chemical oxygen demand (COD) and oil & grease (where they record 613 & Nil mg/l COD and 215 & 5 mg/l oil & grease at the disposal site 3 and the nearest well, respectively).

CONCLUSION

The great industrial development in the study area produces a huge quantity of waste water. This waste water is usually disposed of inadequately in waste disposal sites posing a high risk to the groundwater. Integrated geoelectrical and geochemical methods were used successfully to study the effect of the liquid disposal sites on the groundwater.

The results of the geoelectrical survey in Ghamaza area reveal that the groundwater exists at shallow depths ranging from 7.5 to 10.8 m and the sedimentary section above the water table consists of gravel and sand which permits seepage and filtration from the disposal site to the groundwater. In the western side from the factories area, the groundwater exists at depths ranging from 5 to 9 m and the sedimentary section above it composed of fine sand, and the lower surface of the disposal site 4 matches with the water table in this area so a strong connection between this site and the groundwater exists. On the other hand, in the eastern side from the factories area, the disposal site 3 was excavated in sandy clay and clay beds, so there is no seepages from this site because the oil and grease exist in the liquid wastes in this site coating its inner surface and also the clay layers act as natural barriers.

The 3-D model in Ghamaza area indicate that the southwestern part of the model is affected by the mineral contamination from the disposal site 1 which tend to increase the conductivity and hence decrease its resistivity.

Based on the results of the Vertical Electrical Sounding and the Electrical Resistivity Tomography, seven localities were selected to drill monitoring wells and borehole. The drilling data are strongly matched with the results of the geoelectrical techniques.

In Ghamaza area, the connection between the disposal sites and the groundwater is provided geochemically through comparable values of rCa/rMg of the disposal site 1 (2.72, sample 7) and the monitoring well (1.57, sample 11) as well as values of Fe at the disposal site 1 (3.32 mg/l) and the monitoring well (3.12 gm/l). Also, in the factories area, the presence of MgCl$_2$ at the disposal site 4 (samples 15 & 16) and the shallow groundwater samples (17 & 18); and also the values of Fe in the disposal site 4 (2.95 – 3.2 mg/l) and the monitoring well (1.97 mg/l, sample 18) refer to the strong connection between them.

RECOMMENDATIONS

1- The disposal sites must be excavated in high lands farther to the east in factories area where there is no groundwater due to the presence of clay beds which act as a natural barrier.

2- The disposal sites must be designed and built from impermeable materials to avoid seepages.

3- The changes in the groundwater quality must be observed gradually by using the monitoring wells.

ACKNOWLEDGMENT

REFERENCES

Abdel Shafy, E., Mabrouk B. and Shehata M., 1986, Geological studies on Quaternary sediments in El Saff area with some regional hydrogeological emphasis: Bull. of Fac. of Sci., Zagazig Univ., No. 8, pp 52-76

Al Temamy, A. M., 2011, Groundwater Resources and Potential in Wadi Garawi, East El Teben,Eastern Desert, Egypt: Inferences from Geoelectrical Investigations: EGS Journal, Vol. 9, No. 1, 37-50.

American Society for Testing and Materials (ASTM), 2002, Water and environmental technology: Annual book of ASTM standards, Sec. 11, 11.01 and 11.02, West Conshohocken, U.S.A.

Awad, S. R., 1999, Environmental studies on groundwater pollution in some localities in Egypt: Ph.D. Thesis, Fac. of Sci., Cairo Univ., Egypt.

Barker R.D., 1996, The application of electrical tomography in groundwater contamination studies: EAGE 58th Conference and Technical Exhibition Extended Abstracts, P082.

Bernardes, C.; Hirata, R.; Mendes, J. M. B.; Cleary, R. W., 1991, Remedial Action for an Industrial Open Dump – Proposed Activities and Perspectives. Proc., IAWPRC Intl. Seminar: Pollution, protection and control of groundwater: Water Science and Technology, Vol. 24, No. 11, pp. 271–81.

Campanella, R.G. and Weemes, I., 1990, Development and use of an Electrical Resistivity Cone for Groundwater Contamination Studies: Canadian Geotechnical Journal, 27:5, pp. 557-567.

Campanella, R.G., Davies, M.P. and Boyd, T.J. 1993, The use of in-situ testing to characterize contaminated soil and groundwater systems: Second international Joind ASCE-CSCE Conference on Environmental Engineering, Geotechnical Research Center, Montrial, Vol.2, pp. 1497-1505.

Daly, D., Dassargues, A., Drew, D., Dunne, S., Goldscheider N., Neale, S., Popescu, I.C. & F. Zwahlen, 2002, Main concepts of the European approach to karst-groundwater-vulnerability assessment and mapping: Hydrogeology Journal 10, 340-345.

El Sayed, E.E.A., 1993, Hydrogeological studies of the Nile Valley in the northern portion of Upper Egypt: Ph.D. Thesis, Fac. of Sci., El Minia Univ. 295p.

El Sayed, M. H., Shawky, H. A. and Abd El Moteleb, M.S., 2004, Geochemistry of water resources and pollution problems in Helwan area Egypt: E.J. of Desert, No. 54 Vol.2, p 409-413.

El Sheikh, A.E., 2008, Hydrological assessment of the water logging problem in El Saff-Atfih area, Southeast Cairo, Egypt: Jour. of Geology, Assuit Univ, Egypt, No. 38 Vol. 2, p 159-188.

Fishman, M. J. and Friedman, L. C., 1985, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geol. Surv., Book 5, Chapter A1. Open File Report: 85-495, Denver, Colorado, U.S.A.

Geotomo Software, 2004, RES2DINV Ver.3.54.

Goldscheider, N., 2005, Karst groundwater vulnerability mapping – application of a new method in the Swabian Alb, Germany: Hydrogeology Journal 13, 555-564.

Greenberg, A. E., Trussell, R. P. and Clesceri, L. S., 1985, Standard Methods for the examination of water and waste water: American Public Health Association, Washington, D. C., U.S.A., 16th ed., 886p.

Griffiths D.H. and Barker R.D. 1993, Two-dimensional resistivity imaging and modeling in area of complex geology. Journal of Applied Geophysics,29, 211-226.

Kelly, W.E., 1976, Geoelctric sounding for delineating groundwater contamination: Groundwater Vol. 14, No. 1, pp.6-10.

Loke, M.H. "RES2DINV". V.3.4, 2001, Rapid 2-D resistivity inversion using the least square method: ABEM instruments AB, Bromma, Sweden.

Rainwater, F. H. and Thatcher, L. L., 1960, Methods for collection and analysis of water samples: U.S. Geol. Survey, Water Supply. Paper No.1454, U.S.A., 301p.

Ravbar, N. & Goldscheider, N., 2007, Proposed methodology of vulnerability and contamination risk mapping for the protection of Karst aquifers in Slovenia: ACTA CARSOLOGICA 36/3, 397-411, POSTOJNA

Rowe, D. R. and Abdel Magid, I. M., 1995, Handbook of Wastewater Reclamation and Reuse: CRC press. Inc., 550p.

Said, R. 1981, "Geological evolution of the Nile River ": Springer Verlag, New York, 151p.

Said, R., 1962, "The Geology of Egypt": Elsevier Pub. Co., New York, 377.

Van der Velpen, B.P.A., 1988, Computer program "RESIST" ,Ver.1: M.Sc. Thesis ITC, Delft, Netherlands.

Vías, J.M., Andreo, B., Perles, J.M., Carrasco, F. & I. Vadillo, 2006, Proposed method for groundwater vulnerability mapping in carbonate

(karstic) aquifers: the COP method. Application in two pilot sites in Southern Spain: Hydrogeology Journal 14, 6, 912-

Wang, X.; Ngo, T. X.; Zhou, Y.; Nonner, J. C., 1998, Modelling and Remediation of Groundwater Contamination at the Engelse Werk Well Field: Groundwater Pollution and Remediation, Vol. 18, No. 3, pp. 114–24.

Yousef, A. F., 2007, Geology of groundwater resources in the reclaimed area North of El Saff, Eastern Desert, Egypt: E. J. of Desert Research Center, Matariya, Cairo, Egypt, Vol. 57, No. 1, p 125-

Zohdy, A. A. R.; Eaton, G. P.; Mabey, D. R., 1974: Application of Surface Geophysics to Groundwater Investigations. U.S. Geological Survey, Washington, DC, USA, Techniques of Water Resources Investigations: Book 2, Chap. D1, pp. 1–116.