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Geotechnical and Geochemical Characteristics of the Soils along the Expressway between Damietta and Cairo, from the north to the south of Nile Delta, Egypt.

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ABSTRACT

The purpose of this manuscript is to investigate the geochemical and geotechnical properties of the soils along expressway between Damietta and Cairo, from the north to the south of Nile Delta. The effect of heavy metals on geotechnical properties is very low and can be neglected. Swelling is affected by plasticity index, the clay soil contain high concentrations of heavy metals but the sandy soil contain low concentrations. Most of soils are in safe side for pollution, where, most samples show low degree of contamination and low ecological risk factor.

Keywords: Plasticity index, Swelling, Shrinkage, Nile Delta, Heavy metals, Pollution.

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INTRODUCTION

According to [1] the Nile Delta is the third largest delta in the world with area about 24,000 km^2. The Nile Valley and Delta contain about 95% of the Egyptian peoples (92 millions peoples). The relationship between geochemistry parameters (heavy metal concentrations, organic matter, PH, TDS and EC) and geotechnical parameters is discussed here. Where, the Atterberg limits and swelling will be correlated with the concentration of some heavy metals. In the first, some facts about the Nile Delta must be showed. From the lithological point of view, the surface of Nile Delta area is covered with rocks ranging from gravels to sands, intercalated with clays. The surface geological map of Nile Delta (Fig. 1) showed the type of surface sediments in different locations of the Nile Delta. According to [2] Nile Valley and Delta deposits were classified into three types deposits, these are from base to top; protonile (Q1), prenile (Q2) and neonile (Q3) deposits. The Delta sediments north of Cairo are considered the younger Quaternary Neonile sediments. The shape of the present Nile Delta mainly controlled by many structural elements such as: the Pelusium fault zone in the eastern side [3]. Its western side is Cairo – Alexandria fault zone [4]. [5] reported that the basement of the south delta at 3 – 4.5 Km and from 6 – 9 Km in the central delta. The total thickness of the sediments in the north of delta at the mouths of the Nile is 10 Km [6]. According to [7] and [8,9] the formations of Nile Delta subdivided into eight formations; namely from top to base: Bilqas (newest), Mit Ghamr, El Wastani , Kafr El-Sheikh , Abu Madi, Rosetta, Qawasim and Sidi Salim (oldest). Bilqas formation may be included within the Neonile deposits, which are Late Pleistocene to Holocene [2]. The Nile Delta is subdivided into three zones, namely southern, middle and northern zones. Southern zone contain coarse Nile sediments mainly sand deposits. The middle zone is consists of finer sediments when compared to the southern zone, so it assumed to be a transitional zone between the southern and northern Delta zones. In the northern zone, the finest neonile sediments of the three zones were occurred [10]. An embayment formed in Northern Egypt bordered by the south and southwest cliffs of Cretaceous and Eocene rocks formed during Middle Miocene. The Nile Delta sediments consists of shale and clays with sandstone interbeds, indicating a rapid and continuous deposition in a gradually subsiding basin [11,2]. The age of the Modern Delta is Late Pliocene and Quaternary, it is considered as young feature about 3 million years old. The deltaic deposition of the modern Delta began with the deposition of EL-Westani Formation [12]. The age of EL-Westani Formation is Late Pliocene which overlain by the Pleistocene Mit Ghamr Formation followed by Holocene Bilqas Formation.

According to [13] and [14] the soil must be remediated from heavy metals contamination, where the accumulation of heavy metals in soils are very bad for soil fertility, ecosystem and human and animals health. Most of the soils of Nile Delta are formed from silt and clay. Metal contamination is generally large problem in soils with higher amounts of clay and silt fractions. Clays are more chemically active than the other soil components and this fraction tends to accumulate the largest fraction of metals. When the heavy metals emissions resulted from the rapidly expanding industrial areas the soil well be contaminated. The presence of toxic metals in soil can severely inhibit the biodegradation of organic contaminants [15]. Heavy metals are naturally present in the soil due to geologic and anthropogenic activities. These activities increase the concentration of these metals in the soil to amounts that are harmful to both plants and animals. Heavy metals are with relatively high density and high relative atomic weight with an atomic number greater than 20 [16]. Heavy metals such as Co, Cu, Fe, Mn, Mo, Ni, V, and Zn may be useful in few quantities for organisms. but, excessive of these metals can become harmful to organisms. On the other hand some heavy metals such as Pb, Cd, Hg, and As are very harmful in any quantities to both plants and animals. According to [17] soil pH is the main factor affecting metal availability in soil. Organic matter and hydrous ferric oxide have been shown to decrease heavy metal availability through immobilization of these metals [18]. There are positive relationship between heavy metals and some soil physical properties such as water holding capacity and moisture content [19]. It is known that the presence of one heavy metal may affect the availability of another in the same soil and hence plant. [20] reported that the inhibitory effect of Mn on the total amount of mineralized C was antagonized by the presence of Cd.

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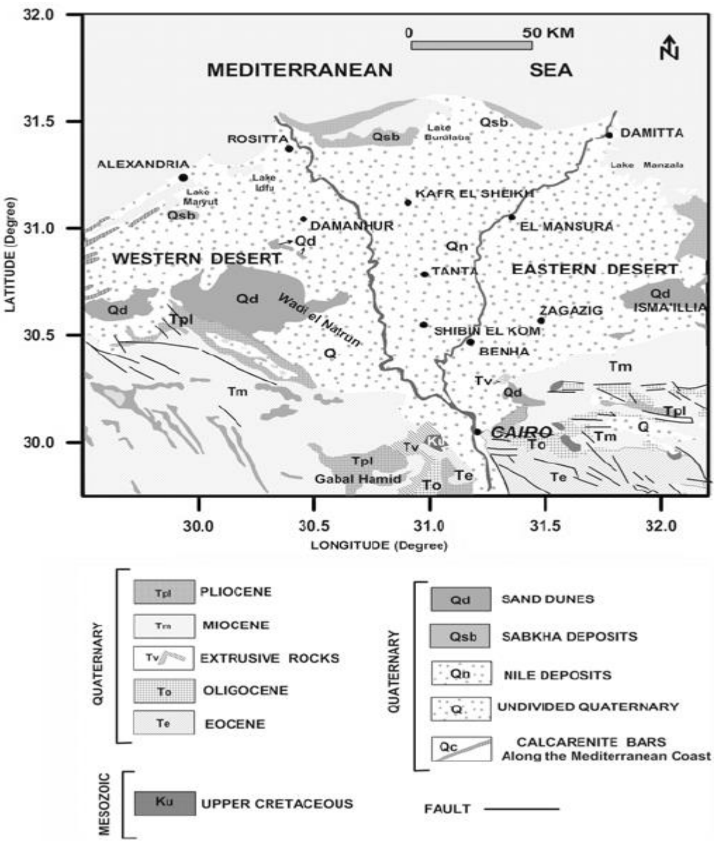

Fig. (1): Surface geological map of Nile Delta region (from [21])

According to [22] many of reactions such as complexation, precipitation, adsorption, oxidation and reduction affect on the behavior of toxic metals in soils. The buffering capacity of soil is related to the ability of soil to retain the metals, where this ability depends on the soil resistance to PH variations [23]. Depending on pH, EC , temperature and soil composition, heavy metals can be retained in the form of oxides, hydroxides, carbonates, or confined in exchangeable cations and organic matter [24]. The fine particles as in clay minerals, where the large surface area and organic matter content are related to the retention capacity by adsorption [25] [24].

The behavior of the soil is related to the amount of water. [26] defined the boundaries of four states in terms of "limits" as follows: Liquid limit, Plastic limit, Shrinkage limit, Liquid limit. [27] classified the plasticity index of soil in a qualitative manner. The plasticity of soil is proportion to its plasticity index. The higher the value of P.I., the higher it's plasticity. Atterberg limits is vary according to the type of clay minerals [28] as in the following Table 1.

Table (1): Atterberg limits values for the clay minerals [28]

Mineral^a	Liquid Limit (%)	Plastic Limit (%)	Shrinkage Limit
Montmorillonite	100–900	50–100	8.5–15
Nontronite	37–72	19–27	
Illite	60–120	35–60	15–17
Kaolinite	30–110	25–40	25–29
Hydrated Halloysite	50–70	47–60	
Dehydrated Halloysite	35–55	30–45	
Attapulgite	160–230	100–120	
Chlorite	44–47	36–40	
Allophane (undried)	200–250	130–140	

Meanwhile, in the book of [29], compressibility of soil can be classified based on its liquid limit. Soil with less than 30% value of liquid limit fall on low compressibility category, between 30% to 50% fall on medium compressibility while liquid limit greater than 50% fall on high compressibility category. The relationship of the plasticity index to the liquid limit of soils (Fig. 2) and proposed a plasticity chart as shown [30]:

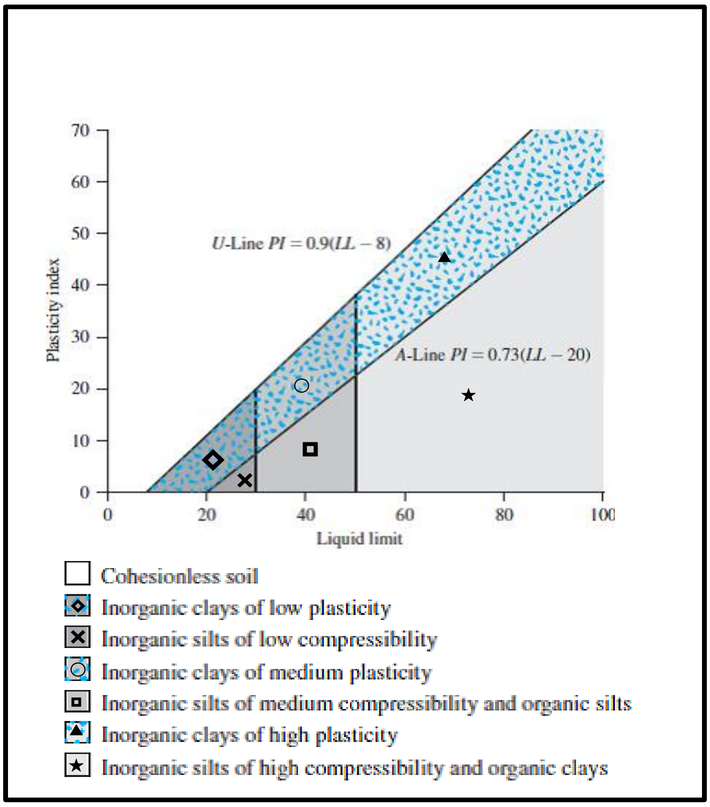

Fig. (2): Plasticity chart according to [30]

In this manuscript, the geochemical and the geotechnical engineering properties are discussed for the soils along the expressway between Damietta and Cairo. Heavy metals concentration, organic matter, PH and swelling as well as Atterberg limits were determined.

MATERIALS AND METHODS

About 11surface soil samples were collected from the Nile Delta in 2016 (Fig.3 and Table.2) along the express way between Damietta and Cairo (from North to South of Nile Delta). These samples subjected to two types of analysis, the Geotechnical engineering analysis and Geochemical analysis. Geotechnical engineering and Geochemical data were recorded and correlated in Tables 3,4. The Atterberg limits, swelling and organic content were performed using BS 1377 (1975). The concentration of heavy metals performed by atomic absorption spectrometer (Perkin Elmer, AAnalyst 400). One gram of the powdered sample was digested with a mixture of H_2O_2, HCl and HNO_3 according to the method described by [31]. PH of soil in the saturated soil paste was measured using Allied type PH Meter Model 830.

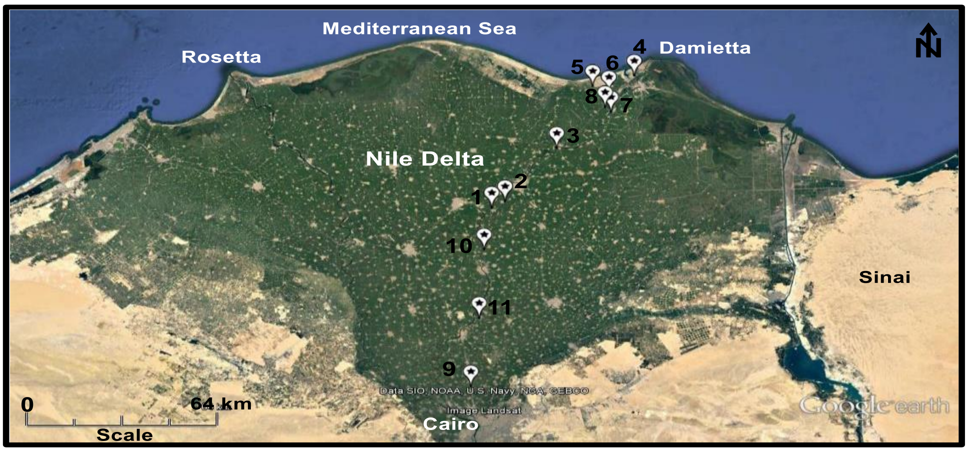

Fig.(3) Location map of the sampling of the study area

Table.(2) Locations of samples in the study area

Samples	Latitude	Longitude	Notes
1	30 57 1.7 N	31 17 8.3 E	On Aga Bridge (far about 10 m from the road)
2	30 58 31.5 N	31 19 55.7 E	After Aga Bridge Between Aga and Mansoura (Right side of road)
3	31 10 49.7 N	31 30 48.7 E	On Sherbeen Bridge (far about 10 m from the road)
4	31 27 34.1 N	31 47 14.9 E	Front to Mobco factory
5	31 25 13.1 N	31 38 27.3E	Between Gamasa and New Damietta City (On the right side toward to New Damietta City)
6	31 23 48.9 N	31 41 52.9 E	On the right side toward to New Damietta City after Gamasa (after the sample5 by 3 km)
7	31 20 18.0 N	31 41 1.8 E	On Farascor Bridge (on the right side toward Farascor)
8	31 19 9.4 N	31 42 16.0 E	Kafr ELArab (Haggaga cultivated bridge)
9	30 15 35.2 N	31 12 43.2 E	Before Cairo by 23 km (on the right side road toward Cairo)
10	30 47 19.9 N	31 15 32.3 E	Before Mit Ghamr by 3 km (on the right side road toward Cairo)
11	30 31 28.3 N	31 14 28.1 E	Kafr Shokr (on the right side road toward Cairo)

Table (3): Concentration of the heavy metals in the soils along the expressway between Damietta and Cairo Cities

Samples	Fe	Mn	Zn	Pb	Cu	Cd	Ni	Cr	Co
1	3082	595	72.8	4.2	36.3	0.5	47	137.8	26.9
2	3113	477	78.5	20	31.8	2.8	59.9	134.7	34.2
3	3378	422	73.9	0	38.2	0	52.2	184.7	29.1
4	2562	148	22.5	0	0	0	0	0	0
5	1925	81	18.6	2.3	51.6	2.4	12.1	7	7.4
6	3137	514	75.4	20.4	46.5	3.2	72.6	173.4	29.6
7	3095	535	76.1	17.2	31.6	2.6	69.9	198.3	32.6
8	1276	137	9.2	0	1.6	0	0	0	0
9	3173	662	77.3	0	42.5	0	35.7	218.5	11.7
10	3061	506	72.6	11.5	36	0.4	53.8	208.2	23.3
11	2882	388	41.5	0	29.6	0	7.3	167.8	0
Means	2504.27	359.18	49.36	5.01	27.2	0.79	30.71	114.27	15.01
Average shale	47200	850	95	20	45	0.3	68	90	19
UCC	30890	527	52	17	14.3	0.1	18.6	35	11.6
Tr	-	-	1	5	5	30	3	2	5

Average shale, after [32], Tr: toxic-response factor of [33], upper Continental crust (UCC) of [34].

Table (4): Geotechnical properties, OM and PH of the soils along the expressway between Damietta and Cairo Cities

Samples	Liquid limit L.L	Plasticity limit P.L	Plasticity Index P.I		Shrinkage	Free swelling F.S.	compressibility	Swell index	PH	OM%
1	82.9	42	40.8	V.H.P	10.15	160	High compressibility	0.070	7.74	2.9
2	69.7	35.2	34.4	H.P	7.31	140	High compressibility	0.057	7.99	1.3
3	68.6	40.2	28.4	H.P	9.15	140	High compressibility	0.046	8.1	1.7
4	More than 95% Sand								8.06	0.9
5	More than 95% Sand								8.46	0.59
6	74.2	37.9	36.3	H.P	5.99	130	High compressibility	0.061	8.32	2
7	79.9	40	39.9	H.P	14.65	150	High compressibility	0.068	8.21	2.3
8	64.7	33.5	31.2	H.P	6.72	120	High compressibility	0.051	8.31	1.3
9	75.8	38.2	37.7	H.P	6.54	140	High compressibility	0.064	8.43	2
10	67.7	31.8	36.5	H.P	8.35	120	High compressibility	0.061	7.79	1.4
11	66	34.3	31.7	H.P	5.30	120	High compressibility	0.052	8.33	2.4

RESULTS AND DISCUSSIONS

Geochemical properties:

Heavy metals pollution:

Distribution of heavy metals in the soils along the expressway between Damietta and Cairo are given in Tables 4. The means of heavy metal contents (Table. 4) are 2504.27, 359.18, 49.36, 5.01, 27.2, 0.79, 30.71, 114.27, and 15.01, Fe, Mn, Zn, Pb, Cu, Cd, Ni, Cr, and Co respectively.

The mean concentrations of heavy metals (Table. 3) in the soils along the expressway between Damietta and Cairo are in the following order: Fe > Mn > Cr > Zn > Ni > Cu > Co > Pb > Cd.

The pollution in the soils along expressway between Damietta and Cairo can be assessed by determining some of indices such as the contamination factors (CF), degree of contaminations (Dc), and ecological risk index (RI) (Table. 5). Potential ecological risk index (RI) depends on the potential ecological risk factor (Er), the toxic-response factor (Tr) and the contamination factors (CF).

Contamination factor (CF) and Degree of contamination (Dc)

Contamination factor (CF) is the level of contamination [33]. The CF is the ratio obtained by dividing the concentration of each metal in the sediment by the baseline or Background value. The background value corresponds to the baseline concentrations reported by [32] and is based on element abundances in sedimentary rocks (shale). The level of contamination for each metals (contamination factor) divided into four categories as following: CF<1, low contamination factor; 1≤ CF <3, moderate contamination factors; 3≤ CF <6, considerable contamination factors; and CF ≥6, very high contamination factor.

Another index that can be derived from the CF values is the degree of contamination (Dc) defined as the sum of all contamination factors for a given site [33]:

$$Dc = \sum_{1}^{n} CF$$

Where CF is the contamination factor, and n is the number of the elements used in the study. When the calculated Dc less than n , low degree of contamination occurred; when n≤Dc<2n, moderate degree of contamination occurred; when 2n≤Dc<4n, the results is considerable degree of contamination; and when Dc>4n, the value is very high degree of contamination [35] and [36].

For the description of the degree of contamination in the study area the following terminologies have been used: Dc < 9 low degree of contamination; 9<Dc<18 moderate degree of contamination; 18≤Dc<36 considerable degree of contamination; Dc > 36 very high degree of contamination. Where, n=9= the count of the studied heavy metals.

In the study area, degree of contaminations (Dc) were low degree of contamination in all samples except sample 2,5 and 7(Moderate degree contamination), sample 6 (considerable degree contamination) (Table 5).

Ecological risk factor (Er) and potential ecological risk index (RI)

Ecological risk factor (Er) is calculated quantitatively for the potential ecological risk of chosen contaminant suggested by [33]

$$Er = Tr \times CF$$

Where Tr is the toxic-response factor for a given metals, and CF is the contamination factor. The Tr values of heavy metals suggested by [33], where Pb=Cu=5, Cd= 30, Cr=2, Zn=1, As=10, Hg=40, Ni= 3, and Co=5. There are many standard terms used to known the risk factor as following: Er<40, low potential ecological risk; 40≤Er<80, moderate potential ecological risk; 80≤Er<160, considerable potential ecological risk; 160≤Er<320, high potential ecological risk; and Er≥320, very high ecological risk.

The potential ecological risk (RI) of the heavy metals is quantitatively evaluated by the potential ecological risk index (Er) [33] and [37], where, (CF), and (Tr) were used.

The results obtained were compared with standards terms of Er and RI of metal pollution risk on the environment suggested by [33] and [38]. The potential ecological risk index (RI) was calculated as the sum of the risk factors (Er).

$$RI = \sum_{1}^{n} Er$$

where Er is the ecological risk factor, and n is the number of the heavy metal. The following values standards were used for the potential ecological risk index: when RI<150, the low ecological risk occurred; when 150≤RI<300, moderate ecological risk occurred; when 300≤RI<600, the considerable ecological risk is occurred; and when RI>600, the very high ecological risk is occurred [33] and [38]. Where, Er and RI denote the potential ecological risk factor of individual and multiple metals, respectively.

The potential ecological risk index (RI) are Low ecological risk (LER) in all samples except samples 5 and 7 (moderate ecological risk) and samples 2 and 6 (considerable ecological risk) (Table 5).

Table (5):Contamination factors (CF), Degree of contamination (Dc) and Ecological risk index (RI) of the soils along the expressway between Damietta and Cairo Cities.

Samples	Fe	Mn	Zn	Pb	Cu	Cd	Ni	Cr	Co	Dc		RI	
1	0.06	0.7	0.76	0.21	0.80	1.66	0.69	1.53	1.41	7.85	LDC	**68.06**	**LER**
2	0.06	0.56	0.82	1	0.70	9.33	0.88	1.49	1.8	16.67	MDC	**303.99**	**CER**
3	0.07	0.49	0.77	0	0.84	0	0.76	2.05	1.59	6.54	LDC	**19.08**	**LER**
4	0.05	0.17	0.23	0	0	0	0	0	0	0.46	LDC	**0.236**	**LER**
5	0.04	0.09	0.19	0.115	1.14	8	0.17	0.07	0.38	10.23	MDC	**249.14**	**MER**
6	0.06	0.60	0.79	1.02	1.03	10.66	1.06	1.92	1.55	18.73	CDC	**345.90**	**CER**
7	0.06	0.62	0.80	0.86	0.70	8.66	1.02	2.20	1.71	16.67	MDC	**284.68**	**MER**
8	0.02	0.16	0.09	0	0.03	0	0	0	0	0.32	LDC	**0.274**	**LER**

9	0.06	0.77	0.81	0	0.94	0	0.52	2.42	0.61	6.17	LDC	**15.04**	**LER**
10	0.06	0.59	0.76	0.575	0.8	1.33	0.79	2.31	1.22	8.46	LDC	**60.77**	**LER**
11	0.06	0.45	0.43	0	0.65	0	0.10	1.86	0	3.58	LDC	**7.77**	**LER**

LDC: low degree of contamination, MDC: moderate degree of contamination, CDC: considerable degree of contamination; LER: low ecological risk, MER: moderate ecological risk, CER: considerable ecological risk

Geotechnical properties:

Geotechnical properties (for all clay samples except sandy samples (4,5)) of the soils along the expressway from Damietta and Cairo (Table. 4) showed the following ranges: Liquid Limit (LL) range from 66 to 82.9, Plasticity Limit (PL) range from 31.8 to 42, Plasticity index (PI) range from 28.4 to 40.8, Shrinkage range from 5.3 to 14.65, Free swelling (FS) range from 120 to 160, Swell Index (Cs) range from 0.046 to 0.070, compressibility is high for all samples. When The liquid limit of the soil is high, the compressibility is high or greater. According to [27] (Table. 6) the plasticity index of soils in the study area are high plasticity (20 < PI > 40) and very high plasticity (PI > 40).

Table. (6): plasticity index categories according to [27]

PI	Description
0	Nonplastic
1–5	Slightly plastic
5–10	Low plasticity
10–20	Medium plasticity
20–40	High plasticity
>40	Very high plasticity

According to [30] plasticity chart (Fig. 4) showed that the soils are inorganic silts of high compressibility and organic clay (MH-OL) with high and very high palsticity. The majority of samples are plotted below the A-line, with LL greater than 60% and PI exceeding 30. One sample (10) only above the A-line (inorganic cohesive clays of high plasticity (CH)). According to this chart the clay minerals of the soils belong to kaolinite (mainly) and illite (rarely).

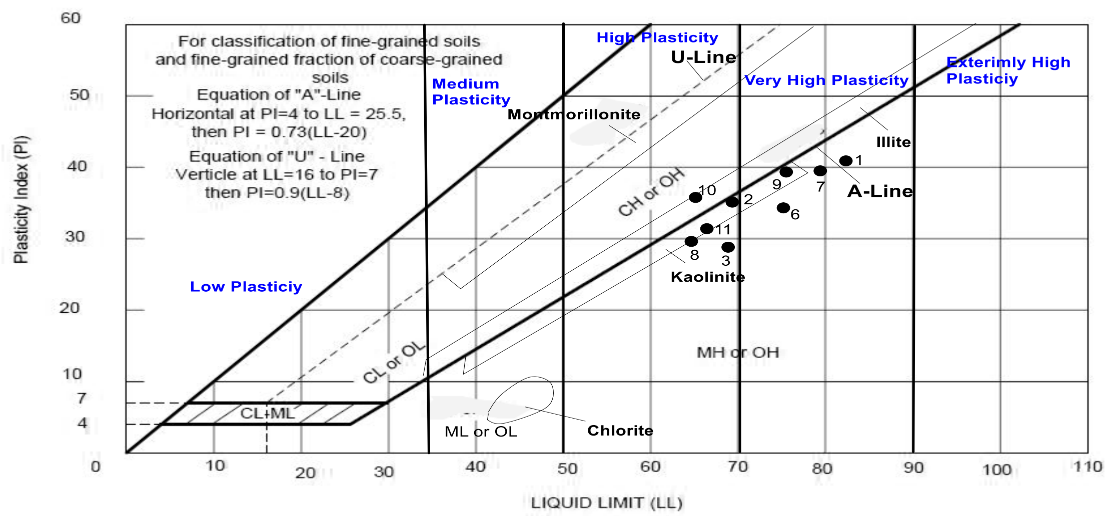

Fig. (4): Plasticity chart of [30] for the soils of Nile Delta along the expressway between Damietta and Cairo.

Liquid Limit (LL) and Plasticity index (PI) are broadly used for evaluating the swelling potential of soil [39]. Swell index (Cs) were estimated by the following equation of [40].

$$Cs = 0.00194 (PI - 4.6)$$

When the soil absorbs water, it will swell and when the water evaporate from soil, it will be shrinks. According to [41] Shrinkage (linear) is decrease with increase the organic matter, where the organic matter tied the particles and decrease the clay content. considerably increase in the moisture content with decrease of the dry unit weight. Swelling and swelling pressure are increased with increase the organic matter. According to [42] the plasticity index is the single best factor to predict swelling potential of soil (Table. 7). Free swelling increases with increasing the clay content and plasticity index, where the clay content is approximately constant in all samples, thus the main factor which affect in the swelling is the plasticity index. Swelling range from 120 to 160 according to the plasticity index (Table. 4).

Table (7): Classification of potential swell according to [42]

Liquid Limit	Plasticity Index	Classification	Samples of the study area
>60	>30	High Potential to Swell	All samples
50 – 60	25- 35	Moderate Potential to Swell	No
< 50	< 25	Low Potential to Swell	No

The relationship between Geochemical and Geotechnical properties:

The liquid limit and Plastic limit of soil increased due to presence of some heavy metals. The amount of increase in liquid limit and plastic limit was found moderate [24]. This relation is not clear in the study area, where the heavy metals concentration were not increase with increase the liquid limit and plastic limit. Thus the effect of heavy metals on engineering properties is very low and can be neglected. According to [43], swelling is increase with increase the organic matter and with decrease fraction sizes of soil as in clay soils. [44] showed that the soil of fine texture such as clay and silt are characterized by higher concentrations of some heavy metals such as Cd, Co, Cr, Cu, Ni and Zn more than in the soil of coarse texture such as sand. Thus in the study area, the clay soils have higher concentration more than in the sandy soils (samples 4 and 5). Soils with low PH levels showed that the metals become mobile and adsorption of heavy metals on clay soils is low or not effective [45, 46 and 47]. According to [48] the heavy metal have a low sorption capacity for the soils due to their sandy texture, low pH and low organic matter content. But in the clay soil with the high organic matter the high sorption capacity occurred. Where the organic matter decrease in samples as following sample1 > sample 11> sample 7> sample 6 = sample 9 > sample 3 > sample 10 > sample 2 = sample 8 > sample 4 > sample 5.

It known that, clay fraction content are more chemically active than the other contents of soil, where the clay fraction tend to attract the largest fraction of metals. Cation Exchange Capacity (CEC) is the amounts of negative charges on the surface of soil fractions, where the clay and organic matter components of soil have negative charges which adsorb and attract the positive charges (cations) by electrostatic force [49]. Thus, [50] suggested that the fertility of soil depend on the large amounts of negative charges, where they retain more cations. In the study area most of samples taken from clay soils with organic matter content, but sample 4 and 5 were taken from sandy soils in the north of the Nile Delta.

Fe and/or Al used as indication for the natural variability of heavy elements in sediments and soils. Where, Fe is sensitive to redox processes, there are a positive relationship between Fe and heavy elements in soils [51, 52]. [53] stated that there are a linear relationship between total concentration of As, Co, Mo, Ni, and Pb and Fe contents in soil as in south of France. Also, [54] suggested that organic matter and clay contents as well as the Fe and Ca content can be used as indication of heavy metals concentrations. In the study area, the organic matter content in clay soil used as indication for concentration of heavy metals as shown in most samples except samples 4 and 5 (Table. 3,4)

CONCLUSIONS

The relationship between the geochemical properties and geotechnical properties of the clay soils along the expressway from Damietta to Cairo showed that the geotechnical properties are considerably affected by geochemical properties. The soils of the study area in category of inorganic silts of high compressibility and organic clay (MH-OL) with high and very high plasticity. The swelling of the clay soils affected by the plasticity index. The heavy metals were highly concentrated in clay soils, but they were in the lower concentration in sandy soils. Most samples show low degree of contamination and low ecological risk factor.

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