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Geotechnical hazardous effects of municipal wastewater on plasticity and swelling potentiality of clayey soils in Upper Egypt

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Abstract

In Upper Egypt, the settled areas were constructed on the flood plain clayey soils which situated on both sides of River Nile course. These clayey sediments are consisting of silts, clays and sands with average values of 47.4, 40.3 and 12.3% respectively and classified as inorganic clays (CL). The clay mineral composition of these inorganic clayey soils constitutes of montmorillonite, kaolinite, illite–montmorillonite mixed layer and minor percents of chlorite and illite. These populated old cities were extended during last three decades in the same time the sewage networks are not found in new extended areas. So that, the private sector was forced to storage wastewater in so called wastewater-tanks below or near the houses. These tanks sometimes filled completely or broken then the wastewater which rich in organic matter will saturate the clayey soils. The wastewater had been caused an increasing in original plasticity and swelling potentiality of these clayey soils. So that, serious damages such as wall cracks and foundation tilting were observed.

Keywords: Wastewater, Clayey soils, Plasticity, Swelling potential, Nile Valley, Upper Egypt

Background

In Egypt, mostly the populated area was constructed over areas covered with flood plain clayey soils which concentrated on both sides of River Nile course and its two branches in the Delta Governorates. These clayey sediments of River Nile floodplain region were deposited during pre-construction of the High Dam. The average thickness of these clayey sediments is 10 m between Aswan and Cairo. These sediments are covered about 4.6 of the total area of Egypt and are characterized by low strength and high compressibility [3].

Mostly, the actual damage to structures due to swelling clayey-soils caused from attracts and absorbs water then swells. The main source of this water is drinking water or wastewater when these lines were broken. In Upper Egypt, the intense increase of population has created a critical need to expand dwelling areas besides the old cities were constructed by the private sector. The absence of a network of sewage in some places and the existence of the so-called tanks for sewage down or near houses considered a serious problem especially when these tanks are broken or filled with wastewater. The wastewater will be absorbed by permeable clayey-soil. This will cause increasing in its natural swelling ability owing to richness of wastewater with organic matter which increases plasticity and swelling potentiality of these clayey-soils. Accordingly, a lot of geotechnical problems in these constructions such as horizontal and diagonal wall cracks and sometimes foundation tilting were recorded (Fig. 1).

Damage and foundation movements caused by expansive clayey soils usually gradually occurred and do not cause rapidly hazardous effects such as hurricanes and earthquakes but often they are much worse, even causing major structural distress [20]. The present

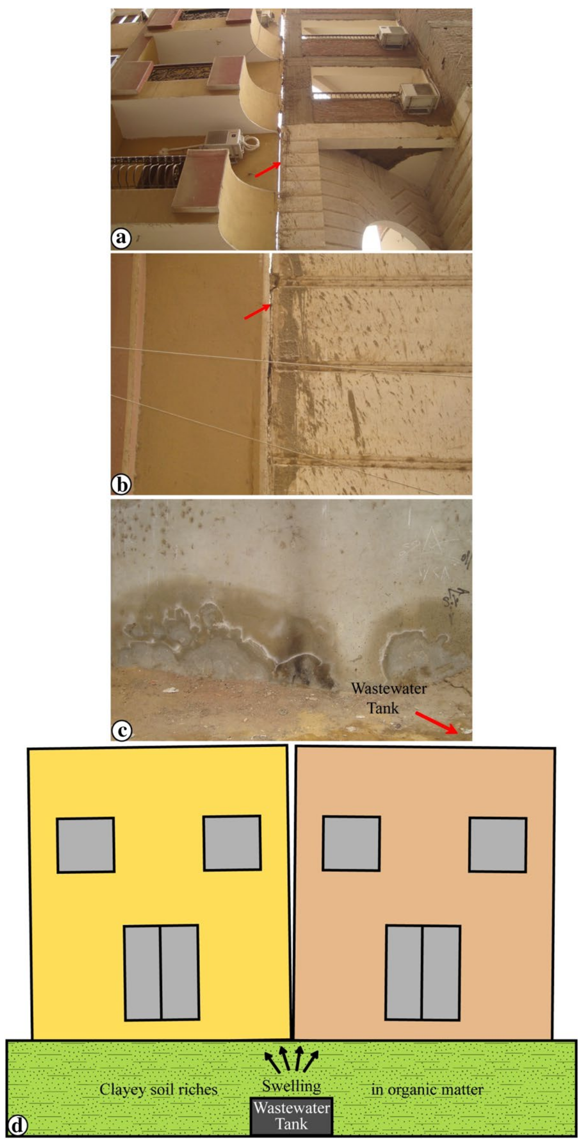

Fig. 1 Types of wastewater clayey soil problems in Sohag Governorate: **a**, **b** tilting owing to differential soil expansion; **c** wastewater saturated clayey soil and **d** a schematic sketch shows enrichment of clayey soil with organic matter from tanks of wastewater

study aims to evaluate the hazardous effects of wastewater on plasticity and swelling potentiality of clayey soil and extended its impact on buildings which were built on this soil.

Location and geologic setting

The studied area is a part of the Nile flood plain of Upper Egypt and extends between latitudes 32°20¯ and 32°15¯ E and longitudes 26°10¯ and 26°45¯ N (Fig. 2). The geology of the study area can be summarized as followings:

1. Lower Eocene carbonates are the most famous and widely distributed rock units in Sohag Governorate, Upper Egypt. Lithologically and paleontological, the Lower Eocene sequences can be subdivided into two rock formations; Thebes and Drunka formations.

    a. Thebes formation was first introduced by Said [36]. It is represented by thick bedded and laminated limestone succession with flint bands.

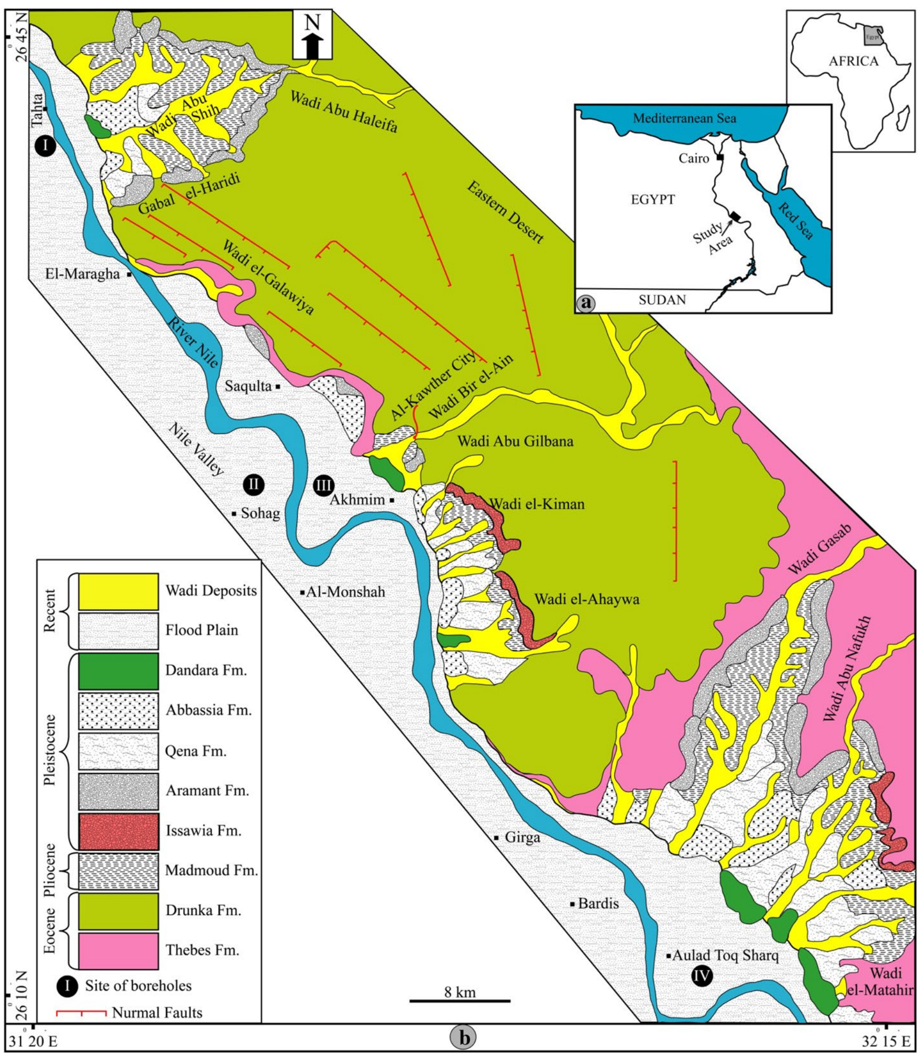

Fig. 2 Location map (**a**) and geological map (**b**) of the studied area. Modified from CONOCO, [21]

b. Drunka formation overlies the Thebes formation and it is easily differentiated by its snowy white colour and massive bedding. As well as, it covers more than 90% of the area around Sohag Governorate [29].

2. Madmoud formation [34, 35] represents the Early Pliocene transgression of the Mediterranean Sea and filling of the Nile canyon.
3. Issawia Formation of the Early Pleistocene [28, 34, 35] crops out along the margins of the Eocene escarpment. It consists of hard red breccias reaching about 10 m in thickness and its breccia clasts ranging from 0.3 to 3 m in diameter [29].
4. Armant formation (Early Pleistocene, [34, 35]) represents in the studied area as coarse-grained sediment terraces of alluvial fans at different heights unconformably overlying Eocene succession. Both Issawia and Armant formations are laterally intertonguing [28].
5. Qena formation [35] exhibits low-topographic hills and consists of a thick succession of sand-gravel association. West of Sohag Governorate, many quarries exploit Qena Formation for construction purposes [2].
6. Abbassia formation [34, 35] is represented by a gravel sequence overlying the Qena Formation on both banks of the River Nile.
7. Dandara formation [35] occurred closer to the cultivated lands and is presented by sand and silt intercalations.
8. Flood plain (cultivated lands) is are mainly restricted to the narrow tract of the River Nile Valley.
9. Recent Wadi Deposits are varying greatly in both the thickness and texture depending on the land morphology and the intensity and regime of the flashflood events forming them [33].

Methodology and test procedures

Forty undisturbed and disturbed samples were collected from four boreholes (I: Tahta, II: Sohag, III: Akhmim and IV: Aulad Toq Sharq, Figs. 2, 3). These samples were immediately covered by wax in situ and kept in a cool place for short period until were used in different tests. The initial moisture water content was determined by heating to 110 °C for 24 h according to ASTM D 2216 [11]. Specific gravity determined according to ASTM 854 [13]. The total organic matters (TOM) of both soil samples and wastewater were calculated by using ignition methods according to ASTM D 2974 [10]. The grain size analysis (gradation) of soil samples was done according to ASTM C136 [9]. The consistency limits (liquid, plastic limits and plasticity index) were done according to ASTM D4318 [12] for both tap water and wastewater treatments. Consequently, swelling behavior of the studied soil samples (swelling pressure and swelling percentage) was done by using odeometer testing [8] for both tap water and wastewater treatments. Also, the free swelling was carried out according to Holtz and Gibbs [26]. The chemical analysis was done by standard methods [18] to determine the exchangeable cations (Na^{+}, K^{+}, Ca^{2+} and Mg^{2+}) for both tap water and wastewater treated soil samples. X-ray diffraction of <0.2 μm was done for representative samples. All above tests (except grain size analysis and X-ray) were done for both the original soil samples and wastewater treated soil samples after soaking in wastewater for 10 weeks.

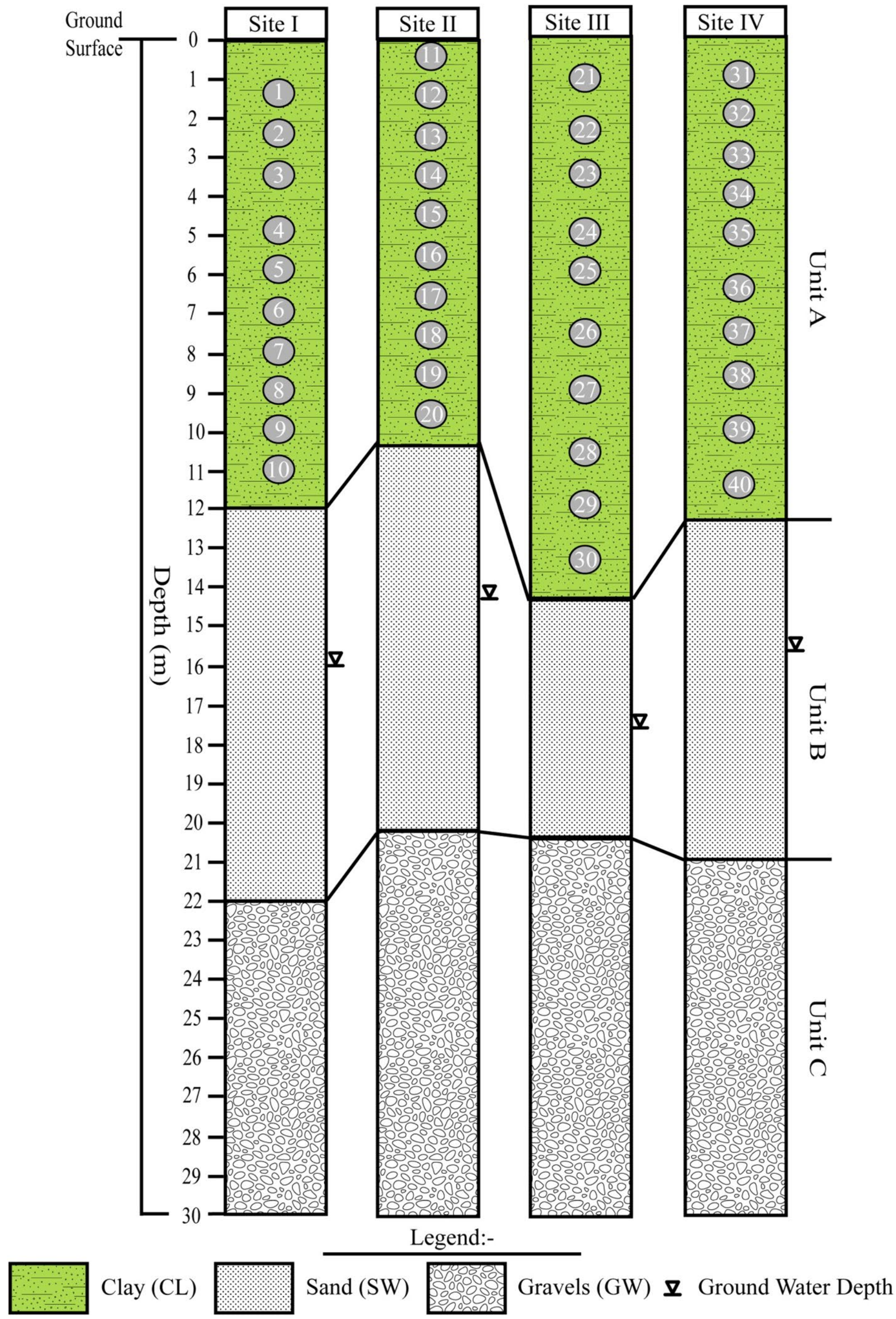

Fig. 3 Typical subsurface profile of the studied sites and sample numbers

Results and discussion

The obtained data of physical properties of the studied soils as well as the effect of wastewater on their plasticity, cation exchange capacity and swelling potentiality will be used in the studied soil classification as the followings:

Grain size

The grain size distribution of clayey sediments plays a vital factor effecting on their swelling potential. The amount of swelling of clayey-sediments increases by increasing the amount of clay-size (<0.002 mm) materials, that due to increasing the specific surface area of these materials. Based on grain size distribution, the soil sequence in the studied area can be subdivided into distinct three units (A, B and C, Fig. 3).

The studied soil samples are predominantly by more or less smoothed grading curves that produce a considerable amount of voids between their particles (Fig. 4). The studied soil samples are consisting of silts, clays and sands with average values 47.4, 40.3 and 12.3%. Furthermore, the studied soil samples were classified as inorganic clays of medium plasticity, sandy/silty/lean clays (CL).

Dry density

The dry density of soil greatly affects volume changes. The initial dry density of the studied soil samples fluctuates from 1.833 to 1.993 gm/cm^3 but the dry density of wastewater treated soil samples ranges from 1.795 to 1.965 gm/cm^3 (Table 1; Fig. 5). It is found that, the dry density of the studied soil samples decreases when soil samples treated with wastewater which rich in organic matter. This observation agrees with many researchers (e.g. [17, 32, 25]).

Clay mineralogy

Both mineral constitutes and clay-sized fractions of fine-grained soil influence its cation exchange capacity, plasticity and swelling potentiality. Generally, the basal spacing of the 2:1 clay minerals influences greatly on plasticity of the clayey soil. The larger the basal spacing of clay mineral species the higher its water adsorption capacity [7, 15, 37]. The water adsorption capacity of smectite-group is larger than kaolinite group owing to its different structure and its greater capacity of water adsorption [16].

The clay minerals composition of fine-grained soil is likely to be the most important controlling factor for many properties and knowledge of the composition may thus simplify problems. Figure 6a shows X-ray diffraction pattern of the studied soil and indicating that montmorillonite (52%), kaolinite (26%) and illite–montmorillonite mixed layer (12%) are the most predominant clay mineral species in all samples. Chlorite (8%) and scarce amount of illite (3% Table 1; Fig. 6a, b) are recorded.

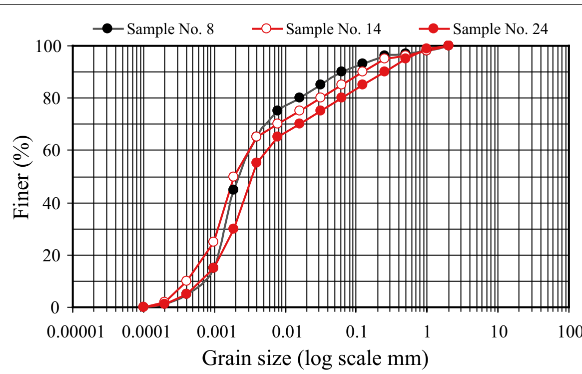

Fig. 4 Grain size distribution curves of the studied soil samples

Table 1 Physico-chemical and mineralogical properties studied soil samples

Site	Sample no.	Depth (m)	Size fractions (%)			Initial water (%)	Dry density (gm/cm^2)		Organic matters (%)		Clay mineralogy species (%)				
			Sand	Silt	Clay		Initial	After wastewater treatment	Initial	After wastewater treatment	Montmorillonite	Kaolinite	Mixed-layer	Illite	Chlorite
I	1	1.5	12	54	34	6.7	1.873	1.845	1.84	3.84					
	2	2.5	13	51	36	9.3	1.853	1.835	2.11	4.15					
	3	3.5	14	51	35	9.8	1.863	1.825	2.01	3.97	53	24	13	8	2
	4	5	12	51	37	10.3	1.883	1.845	2.13	4.18					
	5	6	13	49	38	10.5	1.873	1.835	2.24	3.98					
	6	7	11	53	36	11.5	1.833	1.795	2.11	3.78					
	7	8	13	49	38	11.6	1.873	1.825	2.19	4.18	56	24	11	7	2
	8	9	14	44	42	11.8	1.853	1.825	2.45	4.22					
	9	10	15	48	37	12.1	1.853	1.815	2.11	4.17					
	10	11	12	54	34	5.8	1.853	1.815	1.98	3.91					
II	11	0.5	11	51	38	6.3	1.873	1.835	2.11	3.58					
	12	1.5	10	48	42	6.9	1.893	1.855	2.26	3.94					
	13	2.5	15	46	39	10.5	1.983	1.945	2.33	4.19	53	23	12	9	3
	14	3.5	14	45	41	10.8	1.993	1.965	2.18	3.94					
	15	4.5	12	51	37	11.2	1.953	1.925	2.09	3.78					
	16	5.5	11	51	38	11.5	1.963	1.925	2.07	4.14					
	17	6.5	13	46	41	12.3	1.843	1.815	2.21	4.18	52	26	12	8	2
	18	7.5	11	56	33	12.5	1.863	1.825	1.87	3.64					
	19	8.5	10	54	36	12.5	1.883	1.855	1.95	3.91					
	20	9.5	12	47	41	13.2	1.873	1.835	2.18	4.22					

Table 1 continued

Site	Sample no.	Depth (m)	Size fractions (%)			Initial water (%)	Dry density (gm/cm^2)		Organic matters (%)		Clay mineralogy species (%)				
			Sand	Silt	Clay		Initial	After wastewater treatment	Initial	After wastewater treatment	Montmorillonite	Kaolinite	Mixed-layer	Illite	Chlorite
III	21	1	14	51	35	5.4	1.853	1.815	1.97	4.13					
	22	2.5	12	46	42	9.5	1.853	1.825	2.42	4.31	53	27	12	6	2
	23	3.5	11	45	44	10.5	1.843	1.815	2.56	4.74					
	24	5	13	46	41	11.1	1.853	1.825	2.68	4.92					
	25	6	14	47	39	11.5	1.873	1.835	2.45	4.22					
	26	7.5	15	48	37	12.3	1.863	1.825	2.11	3.98					
	27	9	11	50	39	12.5	1.853	1.825	2.13	4.37	52	24	13	7	4
	28	10.5	12	45	43	12.7	1.843	1.815	2.46	4.62					
	29	12	13	54	33	13.2	1.853	1.815	2.58	4.69					
	30	13.5	8	51	41	13.7	1.843	1.825	2.13	4.79					
IV	31	1	11	47	42	6.4	1.863	1.835	2.23	4.13					
	32	2	10	45	45	8.4	1.863	1.835	2.74	4.19					
	33	3	10	46	44	8.7	1.873	1.845	2.35	4.16	52	26	11	8	3
	34	4	11	42	47	9.5	1.863	1.825	2.61	4.31					
	35	5	13	38	49	9.7	1.883	1.835	2.83	4.56					
	36	6.5	12	37	51	9.7	1.873	1.865	2.91	4.81					
	37	7.5	14	43	43	10.2	1.893	1.855	2.31	4.22	53	26	12	7	2
	38	8.5	10	46	44	10.3	1.868	1.825	2.36	4.12					
	39	10	15	38	47	12.4	1.866	1.835	2.46	3.94					
	40	11	15	32	53	12.5	1.875	1.835	3.11	5.21					

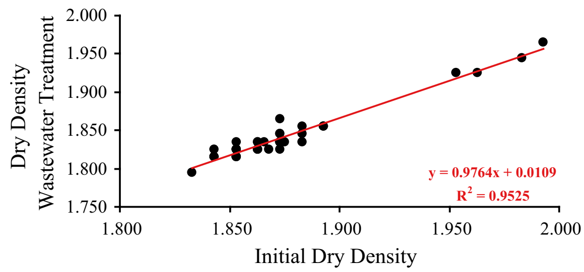

Fig. 5 Dry density of the studied soil samples

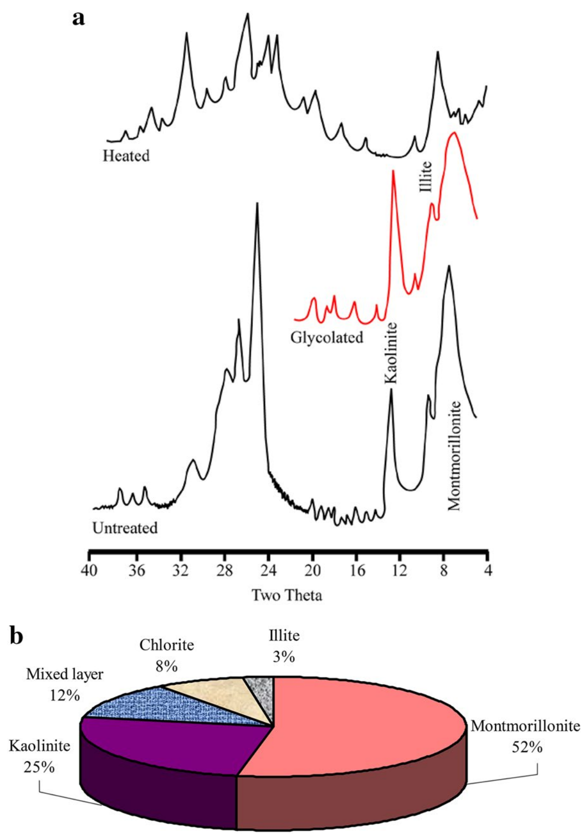

Fig. 6 XRD chart of clay minerals (**a**) and relative abundance of clay minerals species (**b**)

Initial moisture content

Geotechnically, the moisture water content of and fine-grained soil plays a very effective regulation in its capability to expand. The variation in moisture water content of clayey soil causes severe damage to the overlying structures [14, 40, 42–45]. When clayey-rich fine-grained soils are wet, the negatively charged surfaces of 2:1 clay minerals attract positively charged water molecules causing expansion of clay structure. The variation in moisture content is one of the most important factors affecting volume change of dry clayey-rich soil. The thickness of the unit cell structure of clay mineral is relatively small but when moisture water is absorbed into this structure, its thickness increases. The moisture water content of the studied soil samples varies from 5.4 to 13.7% (Table 1).

Consistency limits

From geotechnical point of view, the clayey-soil samples are not classified on the basis of grain size distribution, but according to their plasticity and compressibility. The plasticity characteristics of fine-grained soil are used as fundamentals in classification processes and indirect quantification of soil swell potential. The consistency limits were used as important indicators of engineering behavior and are correlating with the engineering properties of fine-grained soils [24].

The original liquid limit of the studied soil samples is ranging from 39 to 63%, but the liquid limit of wastewater treated soil samples is varying from 66 to 82% (Table 2). That means the soil samples plasticity was increased when treated with wastewater and transformed from clays of medium plasticity (CL) into organic clays of high plasticity (CH, Fig. 7a). The plasticity index of the wastewater treated soil samples is ranging from 34 to 53% (Table 2), so these clayey soils will behave as very high swelling capabilities [19].

Consequently, based on the plasticity index (PI) and clay content (%) values in the Williams [39] chart, the studied flood plain soil samples lie in field of medium exρpansion whereas the wastewater treated soil samples lie in high expansion field (Fig. 7b). The modifications which were took placed in the initial consistency limits of the studied soil samples owing to increasing of organic matters which absorbed from wastewater.

Cation exchange capacity (CEC)

The clayey-rich soils usually carry negative charges these charges owing to occurrence clay particles and organic materials. These negatively charges due to isomorphous substitution of aluminum or silicon atoms of clay mineral particles and balanced by positively cations which present in the water in the void space being attracted to the clay mineral particles. The cations are not held strongly and, if the nature of the water changes can be replaced by other cations, a phenomenon referred to as cation exchange [22]. these positively charged ions (e.g. Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, H^{+} and $NH_4{}^{+}$) required to balance the charge deficiency on the surface of the clay particles [31]. The type of exchangeable cation of a fine-grained soil has a great influence on its swelling potential [6].

Figure 8 illustrates the results for CEC of both untreated and wastewater treated soil samples. Is it clearly found that, the total CEC was increased with treatment processes with wastewater which rich in organic matter and exchangeable cations (Table 2; Fig. 8).

Organic matter

Organic matter plays an important role in soil engineering and physical properties. The increase of organic content increases the soil plasticity as well as increases the cation exchange capacity owing to large surface area [30, 32]. The initial organic matter content of the studied soil samples varies from 1.84 to 3.58% but after wastewater treatment the organic matter content ranges from 3.11 to 5.21%. The humus organic substances of wastewater have a high specific surface and increases initial the plasticity of the studied soil samples (Table 2).

Table 2 Effect of wastewater on cation exchange capacity and consistency limits of the studied soil samples

Site	Depth (m)	Sample no	Total CEC		Consistency limits					
					LL (%)		PL (%)		PI (%)	
			Tap water	Wastewater	Tap water	Wastewater	Tap water	Wastewater	Tap water	Wastewater
I	1.5	1	22	41	41	67	23	29	18	38
	2.5	2	25	43	45	69	24	31	21	38
	3.5	3	23	42	42	68	23	29	19	39
	5	4	24	44	44	69	22	28	22	41
	6	5	27	43	47	70	20	25	27	45
	7	6	23	40	42	67	24	31	18	36
	8	7	26	44	45	69	25	33	20	36
	9	8	29	46	50	74	23	29	27	45
	10	9	24	44	44	69	21	27	23	42
	11	10	23	42	41	67	22	28	19	39
II	0.5	11	24	39	42	66	23	29	19	37
	1.5	12	27	42	45	69	24	31	21	38
	2.5	13	28	45	47	70	25	32	22	38
	3.5	14	26	42	46	70	20	25	26	45
	4.5	15	24	41	39	67	21	27	18	40
	5.5	16	25	43	45	69	22	28	23	41
	6.5	17	26	44	43	70	22	27	21	43
	7.5	18	21	39	39	66	22	29	17	37
	8.5	19	23	42	41	67	20	26	21	41
	9.5	20	26	46	45	71	20	25	25	46

Table 2 continued

Site	Depth (m)	Sample no	Total CEC		Consistency limits					
					LL (%)		PL (%)		PI (%)	
			Tap water	Wastewater	Tap water	Wastewater	Tap water	Wastewater	Tap water	Wastewater
III	1	21	23	44	41	69	21	26	20	43
	2.5	22	29	47	51	73	24	31	27	42
	3.5	23	31	51	54	75	24	32	30	43
	5	24	32	52	56	78	23	29	33	49
	6	25	29	46	50	73	24	31	26	42
	7.5	26	24	43	42	70	24	32	18	38
	9	27	25	48	45	71	20	25	25	46
	10.5	28	29	49	52	73	23	29	29	44
	12	29	31	51	50	74	25	33	25	41
	13.5	30	25	52	43	71	24	30	19	41
IV	1	31	27	44	45	68	24	31	21	37
	2	32	32	46	52	73	24	32	28	41
	3	33	28	44	43	69	20	26	23	43
	4	34	31	47	54	73	21	27	33	46
	5	35	33	49	57	75	20	25	37	50
	6.5	36	34	52	59	80	21	27	38	53
	7.5	37	27	46	45	70	24	31	21	39
	8.5	38	28	44	48	71	24	32	24	39
	10	39	29	43	47	68	25	34	22	34
	11	40	36	58	63	82	34	46	29	36

Tap water (pH = 7.2, TDS = 678 ppm) and wastewater (TDS = 2340 ppm, organic matter = 4.74%)

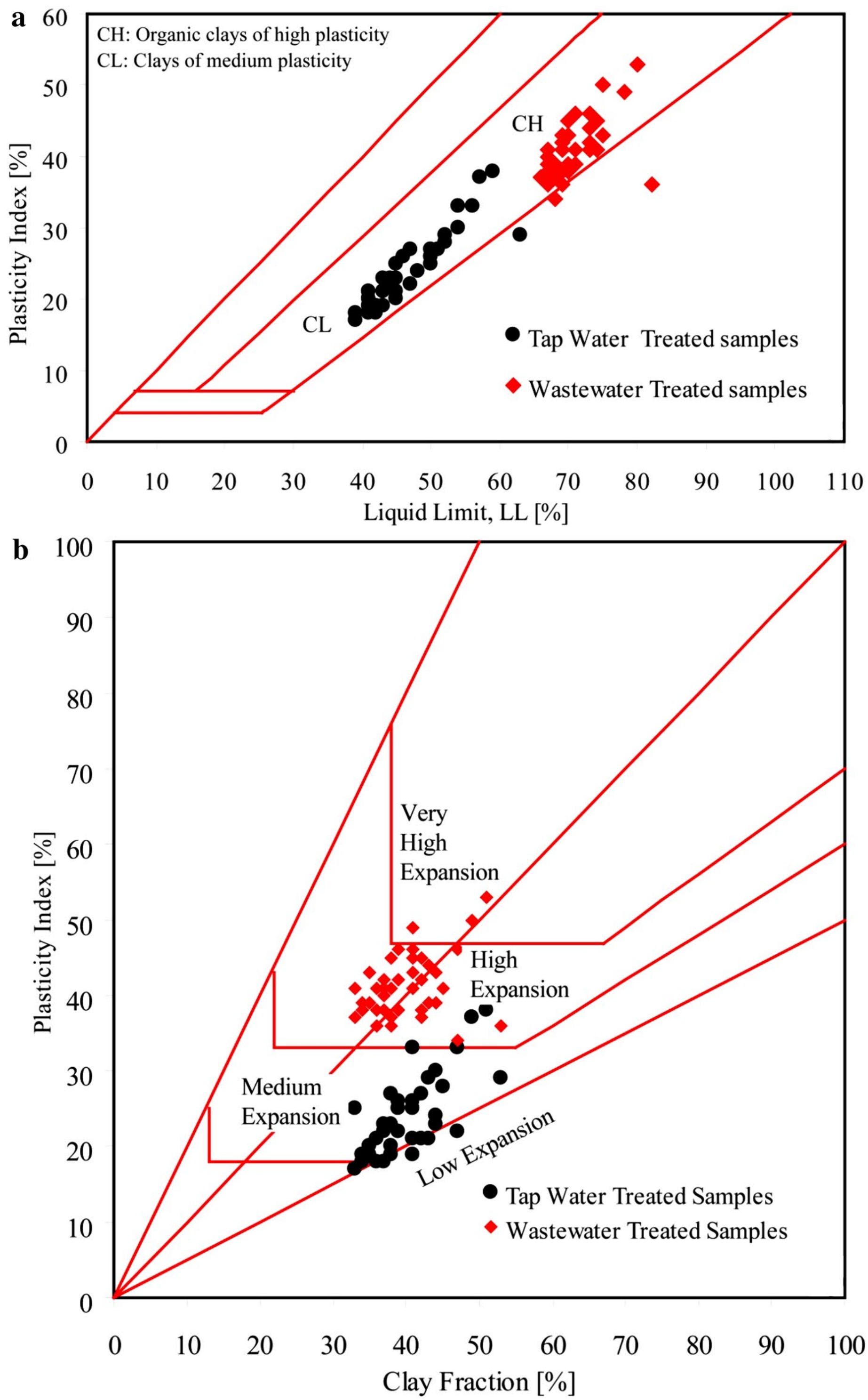

Fig. 7 Plasticity chart of the studied samples based on Dakshanamurthy and Romana, [23] and swelling potential classification (after [39]) (**a** and **b** respectively)

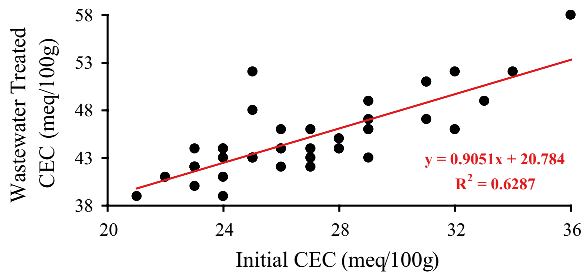

Fig. 8 Initial CEC versus wastewater treated CEC (meq/100 g) (**a**, **b** and **c** respectively)

Swelling characteristics

Swelling pressure

The swelling pressure of the studied undisturbed soil samples was measured directly by: axial free swelling, percentage of swell using the standard one-dimensional odometer apparatus using the following equation:

$$P_S = \frac{P}{A} \tag{1}$$

where P_S = swelling pressure (kN/m^2), P = load (kg), A = cross sectional area (m^2).

The swelling pressure of both untreated and wastewater treated soil samples was found to be (196.1–348.1 kN/m^2), and (382.5–549.2 kN/m^2) respectively (Table 3; Fig. 9a).

Swell percent

The swelling percentage is defined as the percentage ratio between the increasing in specimen height (ΔH) under a standard stress to the initial height of specimen (H_0). The swell percentage is calculated as follows:

$$S = \frac{\Delta H}{H_0} \times 100 \tag{2}$$

where S = swelling percentage, H_0 = initial height of the sample (mm), ΔH = increasing in the height of the sample (mm).

The swelling percentages of the studied soil samples are ranging from 21 to 26%, and 37 to 47% for untreated and wastewater treated soil samples respectively (Table 3; Fig. 9b).

Free swelling

The free swell test was carried out as described by Holtz and Gibbs [26]. The free swell test value is given by:

$$\text{Free swelling value (\%)} = \frac{V_2 - 10}{10} \times 100 \tag{3}$$

where V_2 is in cm^3.

A significant higher free swelling value was observed in experiments carried out using wastewater treated soil samples. The free swelling values of the studied soil samples are 64–73%, and 81–92% for untreated and wastewater treated soil samples respectively (Table 3; Fig. 9c).

Table 3 Effect of wastewater on swelling properties of the studied soil samples

Site	Depth (m)	Sample no	Swelling characteristics					
			Free swelling (%)		Swelling pressure (kN/m^2)		Swelling percent	
			Tap water	Wastewater	Tap water	Wastewater	Tap water	Wastewater
I	1.5	1	67	84	205.9	407.0	22	39
	2.5	2	69	87	210.8	423.6	24	43
	3.5	3	71	89	215.7	413.8	25	45
	5	4	72	91	221.6	436.4	26	47
	6	5	65	82	225.6	426.6	22	39
	7	6	68	86	220.6	398.1	23	41
	8	7	64	81	230.5	436.4	23	42
	9	8	69	87	255.0	460.9	23	43
	10	9	69	87	225.6	433.5	24	42
	11	10	67	84	220.6	419.7	24	44
II	0.5	11	70	88	235.4	423.6	24	43
	1.5	12	71	89	255.0	436.4	22	39
	2.5	13	68	86	245.2	402.1	24	42
	3.5	14	68	86	249.1	416.8	22	39
	4.5	15	69	87	231.4	404.0	23	41
	5.5	16	71	89	239.3	423.6	24	42
	6.5	17	72	91	250.1	436.4	24	44
	7.5	18	71	89	196.1	382.5	22	40
	8.5	19	71	89	217.7	419.7	21	37
	9.5	20	72	91	249.1	460.9	22	38
III	1	21	71	89	217.7	452.1	22	39
	2.5	22	69	87	255.0	470.7	24	42
	3.5	23	69	87	264.8	509.9	23	43
	5	24	68	86	259.9	485.4	25	45
	6	25	68	86	245.2	462.9	23	41
	7.5	26	67	84	229.5	421.7	23	39
	9	27	67	84	239.3	485.4	24	41
	10.5	28	68	86	258.9	496.2	24	42
	12	29	68	86	199.1	465.8	24	42
	13.5	30	71	89	245.2	480.5	23	43
IV	1	31	72	91	255.0	451.1	26	45
	2	32	73	92	269.7	462.9	24	41
	3	33	73	92	264.8	463.9	22	38
	4	34	68	86	284.4	474.6	23	40
	5	35	68	86	294.2	487.4	22	39
	6.5	36	68	86	304.0	534.5	23	41
	7.5	37	67	84	255.0	462.9	23	42
	8.5	38	67	84	264.8	452.1	22	40
	10	39	67	84	284.4	436.4	23	39
	11	40	71	89	348.1	549.2	23	41

Tap water (pH = 7.2, TDS = 678 ppm) and wastewater (TDS = 2340 ppm, organic matter = 4.74%)

When the values of swelling pressure of untreated soil samples were compared with the values of treated soil samples, it was found that, a significant higher swelling pressure was observed in experiments carried out using wastewater treated soil samples (Fig. 10).

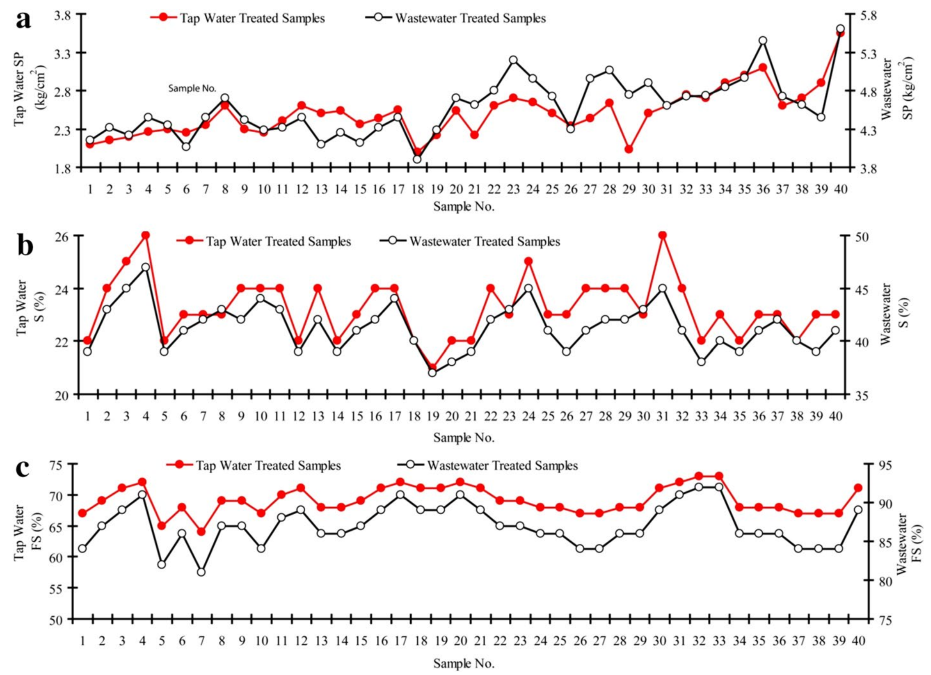

Fig. 9 Effect of waste water on swelling properties; swelling pressure, swelling percent and free swelling and respectively of the studied soil samples (**a**, **b** and **c** respectively)

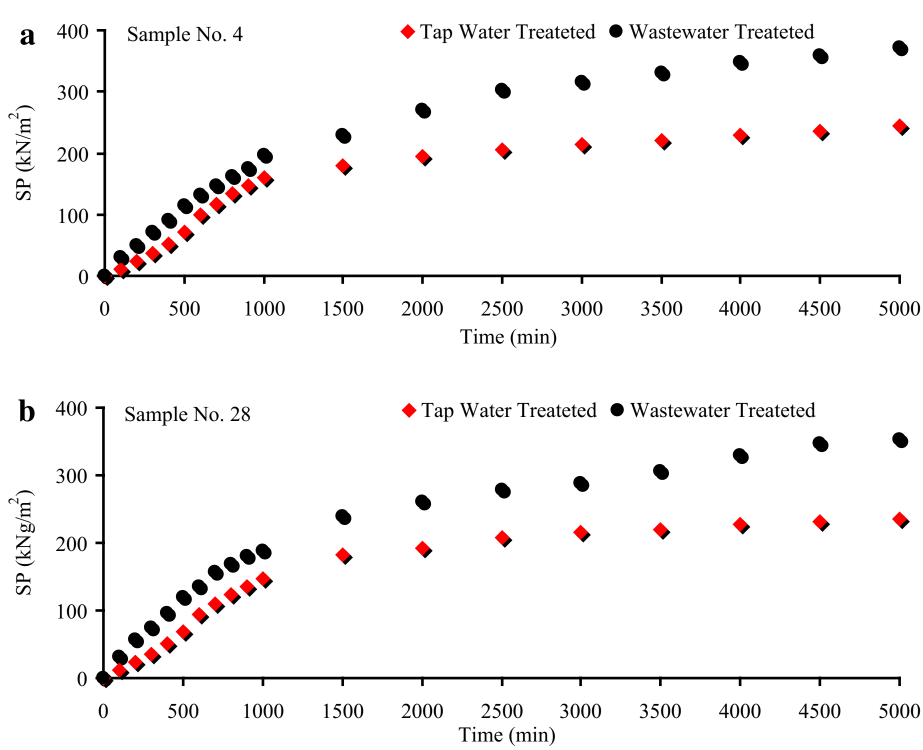

Fig. 10 Swelling pressure versus time obtained from the swell tests of some selected samples (**a** and **b** respectively)

Similarly, respective swell percents were increased (Fig. 11). The swelling of clayey soil when it is subjected to moisture increase is a complicated process found to be influenced by several factors. The swelling percent will be insignificant for initial moisture content slightly higher than the optimum moisture content [19]. As noticed in Figs. 10 and 11, the swelling pressure and swelling percent of the studied clayey soil samples increased when moisture and organic matter content increase.

Correlations between some properties

In the last decay, many researchers were performed to correlate the physical properties with the mechanical properties of soils [1, 4, 5, 27, 38, 41]. This approach was adopted from the earlier researcher in the field of soil mechanics and foundation engineering. These correlations have been considered as a significant part of this work for better understanding of the controlling parameters of plasticity and swelling potentiality of the studied clayey soils. It is clear that, the swelling pressure (kg/cm^2) of both initial soil samples (ISS) and wastewater treated soil samples (WTSS) had significant correlations with clay-sized materials percent, organic matter content, liquid limit (%) and CEC (Fig. 12). Furthermore, the CEC has a significant correlation with clay-sized materials percent, organic matter content and liquid limit (%) respectively (Fig. 13).

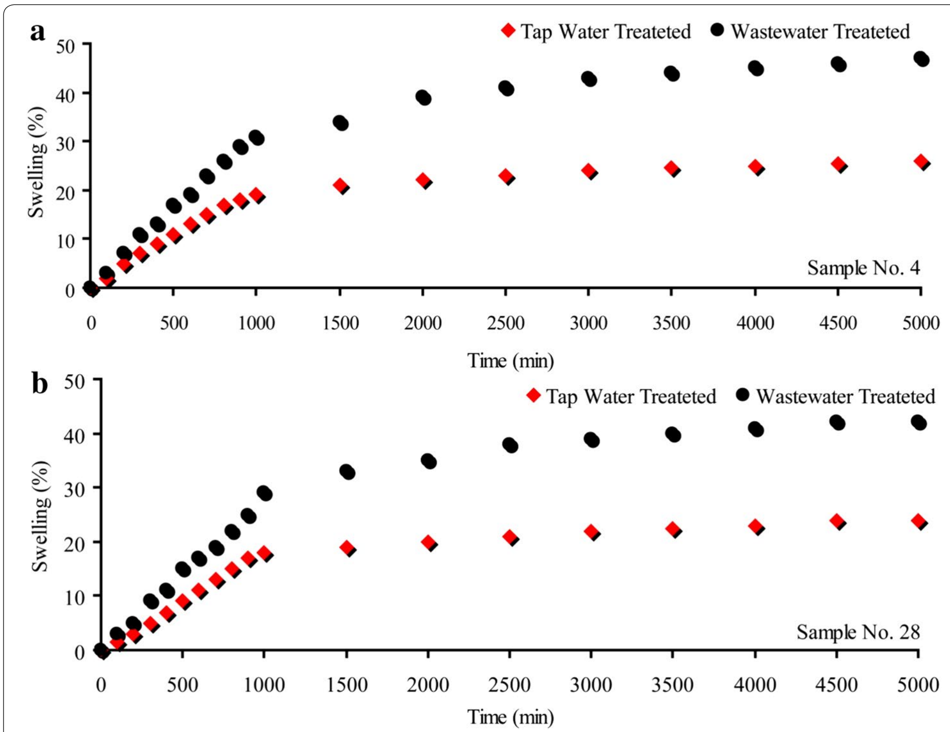

Fig. 11 Swelling percent versus time obtained from the swell tests of sample No. 4 and 28 (**a** and **b** respectively)

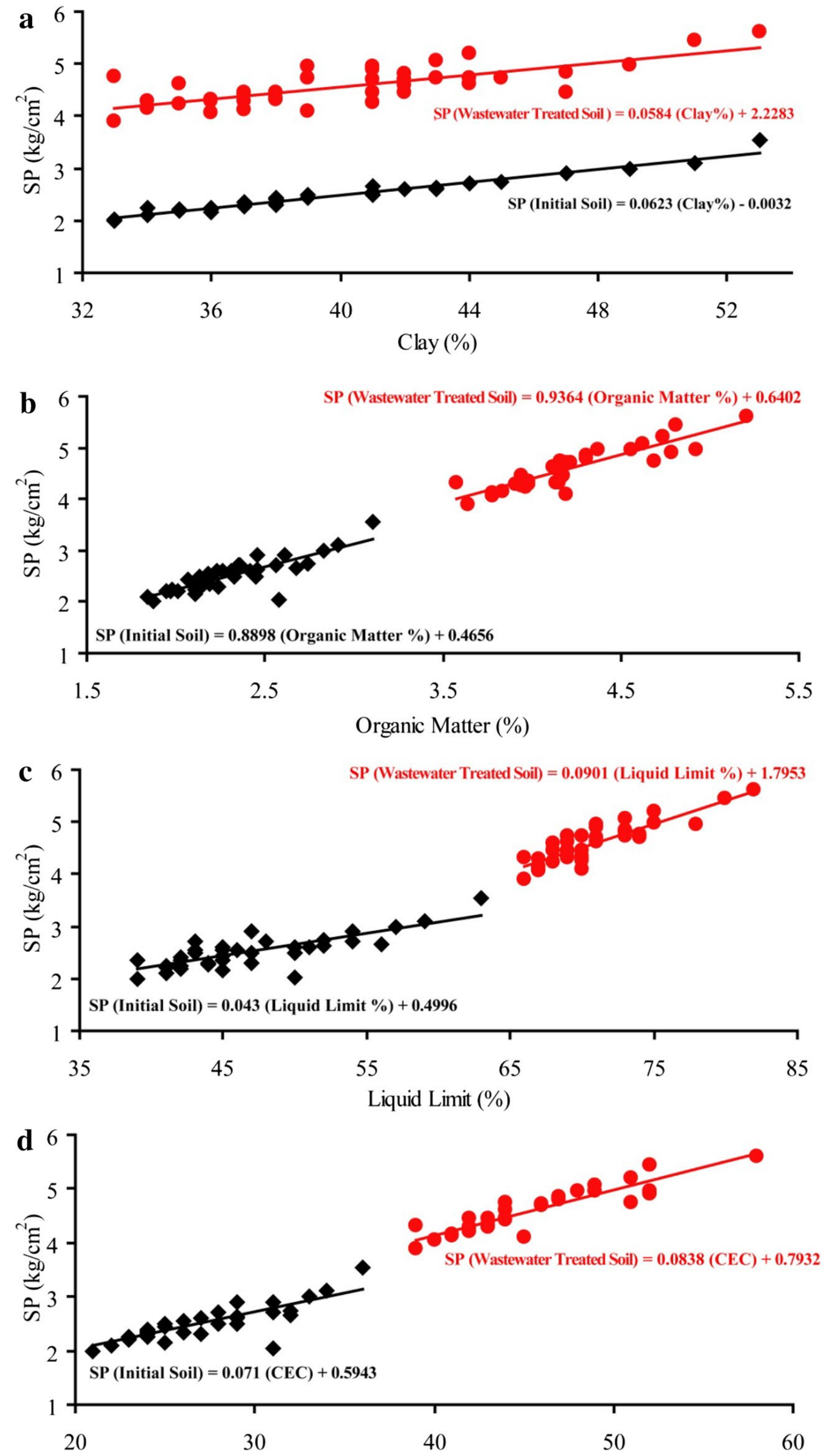

Fig. 12 Swelling pressure versus clay-sized materials, organic matter content, liquid limit (%) and cation exchange capacity of both initial soil sample and wastewater treated soil samples (**a**, **b**, **c** and **d** respectively)

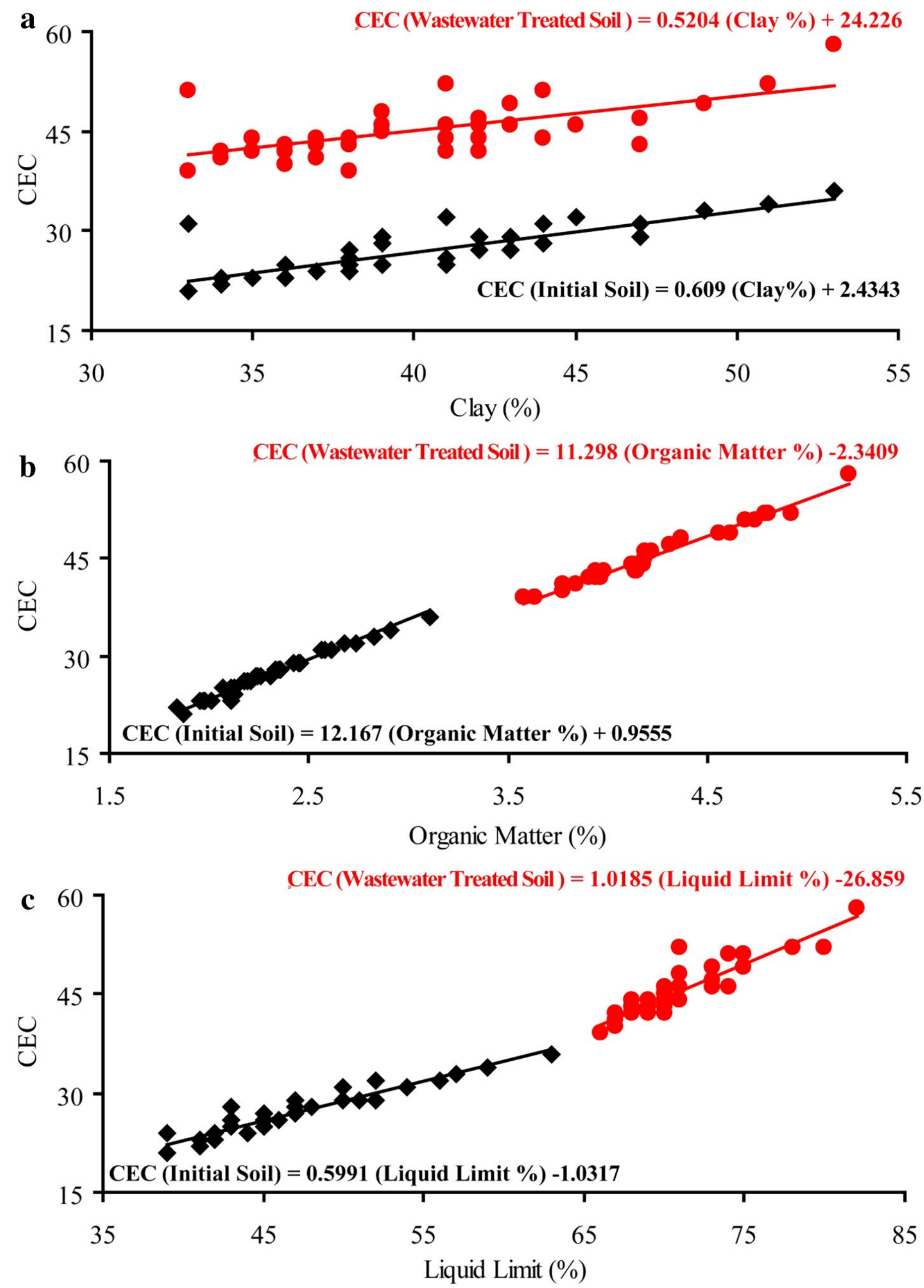

Fig. 13 Cation exchange capacity versus clay-sized materials content, organic matter content and liquid limit (%) of both initial soil sample and wastewater treated soil samples (**a**, **b** and **c** respectively)

Conclusions

The current work can be considered as a model for the effect of wastewater on the plasticity and swelling behavior of clayey soil. The above mentioned results allow getting the following conclusions:

1. The flood plain sediments in Sohag Governorate, Upper Egypt can be subdivided into three distinctive units: inorganic clays (CL), well-graded sand (SW) and channel gravels (GW).

2. Mineralogically, the studied soils are composed mainly of montmorillonite (52%), kaolinite (26%), illite–montmorillonite mixed layer (12%) chlorite (8%) and illite (3%).
3. The original plasticity and swelling plasticity potentiality of these clayey soils are strongly correlated with clay-sized materials percent, organic matter content, liquid limit (%) and CEC.
4. The wastewater has great effects on both original plasticity and swelling plasticity potentiality of these clayey soils and changed these soil from medium plasticity and swelling potentiality into highly potentiality.
5. To reduce the geotechnical hazardous effects of municipal wastewater a good sewer net must be done beforethe beginning construction processes.

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Competing interests
The author declares that he has no competing interests.

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