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Membrane Manufacturing, Testing and Evaluation in Brackish Water Desalination in the Arid Regions: A Case Study in Wadi El-Assiuti, Upper Egypt

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Abstract: The present study is to evaluate the hydrochemical data of groundwater in the different aquifers of Wadi El-Assiuti (Quaternary Deposit and Paleogene Carbonate). The study area is located in the eastern side of the River Nile faced Assiut town, Egtpt. This area mainly depends on the groundwater in drinking and irrigation, which suffers from high salinity water supplies. The aim of the present work is a trial to overcome the high salinity water resources problem in Wadi El-Assiuti area which suffers from this problem through synthesis, characterization and evaluation of modified membrane. Cellulose acetate (CA) and Polyamide (PA) were selected as polymer substrates and modified by blending with polyethylene glycol (PEG) and grafting with acrylic acid (AAc) by dry casting method using two different initiation techniques (radiation and chemically initiated processes). The synthesis of reverse osmosis membranes, their characterization and application in desalination processes were studied. The present work is also mainly devoted to study the possible application of synthetic reverse osmosis membrane in desalination of brackish and saline groundwater in the study area, which is considered as an example of a remote area for development.

Key words: Hydrochemistry · Groundwater · Desalination · Membranes · Semi-arid · Egypt

INTRODUCTION

Warning of a groundwater crisis with falling groundwater tables and degradation of quality have led to calls for urgent management responses. Due to the continuous increase of water demands for domestic and agricultural purposes in Wadi El-Assiuti, groundwater will suffer from continuous degradation in both quantity and quality. The Quaternary aquifer system is of vital importance for the development of the desert fringes of the Nile Valley, where the River Nile is incapable to fulfill the water demands in these areas. Wadi El-Assiuti is a famous dry valley intersecting EL-Maaza limestone Plateau, which predominates the central part of the Eastern Desert of Egypt and extending in a trend of SW-NE. It debouches towards the Nile Valley, nearby Assiut Town (Fig. 1). Outside the Nile Valley and towards the desert fringes, the aquifers are characterized by limited recharge and deprived water qualities and quantities [1-4].

The increasing population in Egypt, the limitation of the surface water resources (mainly Nile River) and, accordingly, the cultivable lands in the Nile valley and Delta urged the successive governments to draw various programs for land reclamation in desert areas. Such programs, mostly, depend totally or partially on local groundwater resources in desert areas and the development of non-conventional water resources such as reuse of water and desalination of saline water.

Therefore, the present study is conducted to evaluate the hydrochemical data of groundwater in different aquifers at Wadi El-Assiuti area. The study is also devoted to synthesize and characterize the reverse osmosis membranes prepared by means of radiation and chemical initiation graft polymerization of different monomers such as acrylic acid into different polymers such as cellulose acetate and polyamide. The possible application of such membranes in desalination of brackish and saline groundwater of Wadi El-Assiuti area is investigated.

Hydrogeological Conditions: According to the data obtained from well logging and composite logs of drilled wells, rock samples of the new observation wells and the aquifer hydraulic parameters, chemical analyses and the

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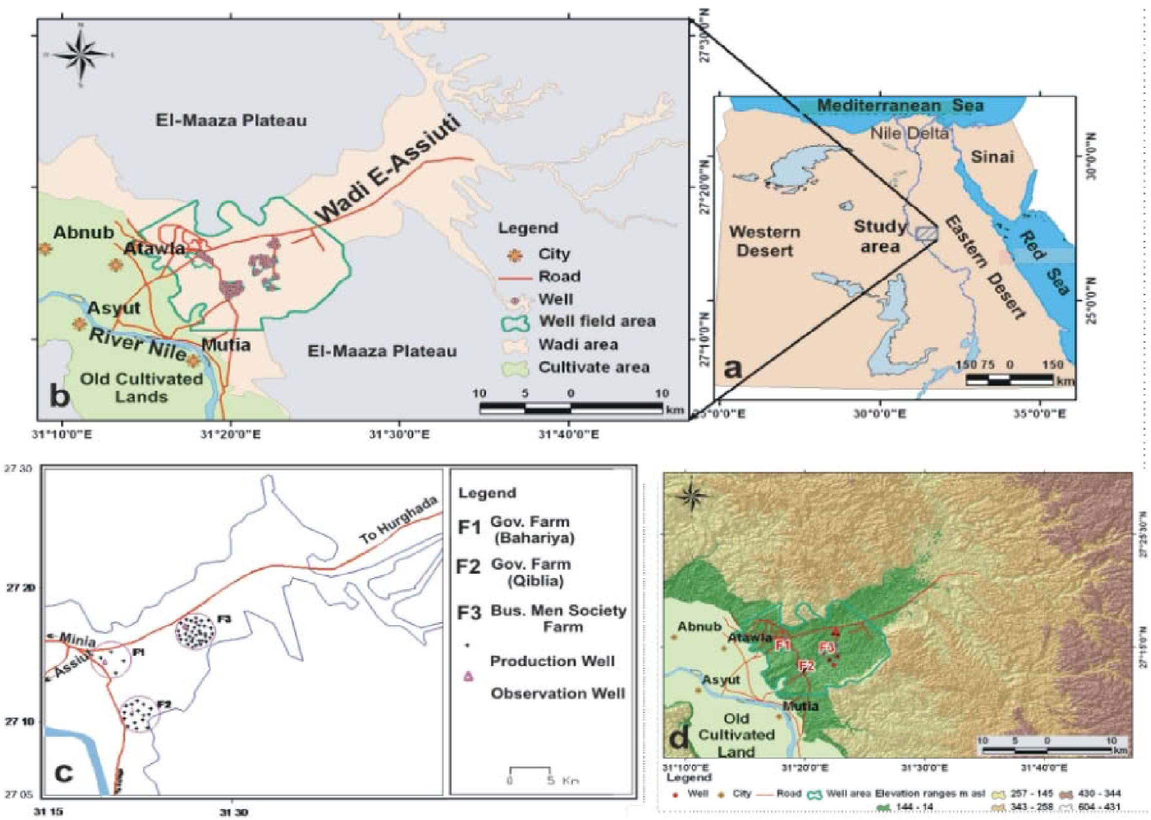

Fig. 1a: Location map of the study area; b Location of mapped area; c Location of the studied well fields; d Digital elevation model (DEM)

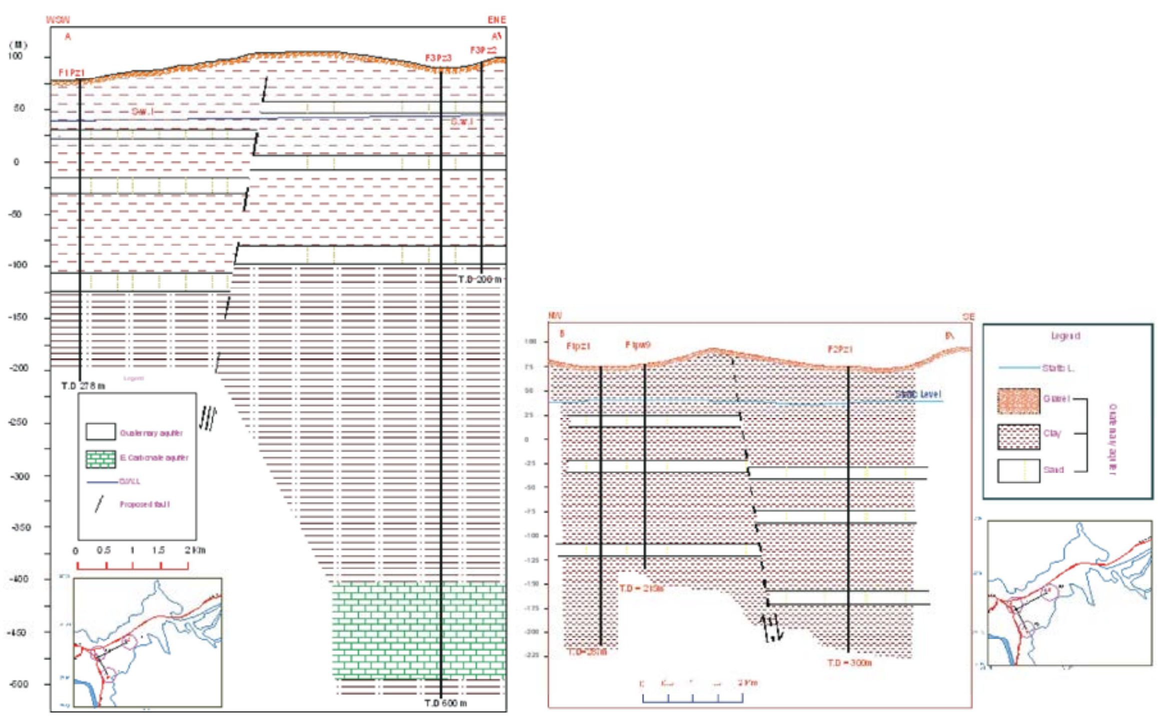

Fig. 2a: Hydrogeological cross section A-A/ Fig. 2b: Hydrogeological cross section B-B/

hydrogeological cross section. Two main aquifer systems could be differentiated in the study area; the Quaternary granular aquifer system and the Eocene carbonate aquifer system (Fig. 2a, b) as described in the following.

The Quaternary deposits in the study area are considered as shallow aquifer. It is composed mainly of coarse to medium sand in the eastern part and medium to fine sand in the western part. Its thickness varies from about 50 m in the eastern part to about 70 m in the western part. Its salinity varies from about 407 ppm in the eastern part to about 2075 ppm in the western part. The main source of recharge is from the direct rainfall which falls down over the catchments area and the deep upward leakage from the Nubian sandstone aquifer through deep major faults.

The carbonate beds are exposed on the surface of the study area and represented by the outcrop of Paleogene and Neogene carbonate sediments and also found in sub-surface as Paleogene carbonates. The carbonate layer is recorded only in the western part at depth 490-680 m. It consists of the dolomitic limestone of moderate permeability and can be store and transmit water in and through the fissures and fractures. This carbonate layer could be recharged through upward leakage from the Nubian aquifer through deep major faults. It has groundwater salinity reach to 19762 ppm. This excessive salinity may possess marine origin and have the effect of leaching processes.

MATERIALS AND METHODS

First of all, the current work includes chemical analysis of major constituent of groundwater for different aquifers in the study area. Secondly, the present work includes the synthesis of reverse osmosis membrane using Cellulose acetate (CA), polyamide (PA)) and polyethylene glycol (PEG) as substrates. Acrylic acid (AAc) is used as monomers. Direct radiation using Co^{60} Gamma ray and also using chemical initiators are used. After that, the casting solution is casted on glass plate. During casting, the solvent is partially removed by evaporation. After the casting step, the membrane is immersed in hot water bath for removing the traces of organic solvent and other leachable compounds.

Characterization of the synthetic membrane is carried out by evaluating the swelling behavior, mechanical properties (tensile strength, elongation %), thermal stability through thermo-gravimetric analysis (TGA), X ray diffraction, FT-IR spectroscopy and morphology changes by scanning electron microscope (SEM). Also, attempts were performed for the desalination of some brackish and saline water samples, collected from the studied area, using the reverse osmosis membranes which acquire the best characteristics. To achieve this work, field and laboratory activities were carried out.

- Collecting groundwater samples from different wells with special emphasis on those having different salinity levels (brackish-highly saline) to be used in the desalination process.
- Carrying out the chemical analysis for all the collected water samples according to the methods adopted by [5] and the methods described by [6] to determine the concentrations of major constituents such as Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, $CO_{3,}$ HCO_3^{-}, SO_4^{2-} and Cl^{-}.
- Preparation of reverse osmosis membranes by dry casting method.
- Evaluation of the characteristics of the synthetic reverse osmosis membranes.
- Studying the possible application of the prepared reverse osmosis membranes in the desalination of brackish and saline groundwater samples.
- Re-analysis of the water samples during and after the desalination process.

RESULTS AND DISCUSSION

Geochemistry of Groundwater: Generally, the chemical composition of the groundwater reflects its origin and history. On the other hand, the quality and chemical assessment of this resource gives insight into its potential for agricultural and/or domestic uses and environmental, geological and hydrogeological impacts on its chemistry. In the present study, the hydrochemical investigation depends on the analysis results of thirty five fife water samples which were collected from the study area. The chemical analysis results of the groundwater samples are shown in Fig. 1 and Table 1.

Total dissolved salts (TDS) in the groundwater is mainly affected by the prevailing hydrogeological condition in the aquifers in addition to some external factors. In the analyzed samples, water salinities ranged between 407 ppm and 19762 ppm. It can be considered generally as slightly brackish water. The western area, Paleogene carbonates aquifer, is dominated by definitely brackish to saline water.

Synthesis and Characterization of Reverse Osmosis Membranes: From the study of the geochemistry of groundwater, it can be indicated that; the main problem

Table 1: The chemical analysis results of the groundwater samples

Well no.	*Aquifer*	*pH*	*TDS*	*Unit*	*Ca^{2+}*	*Mg^{2+}*	*Na^{+}*	*K^{+}*	*Total cations*	*CO_3^{2-}*	*HCO_3^{-}*	*SO_4^{--}*	*Cl^{-}*	*Total anions*
1		8.47	407	ppm	47.17	24.92	62.00	11.0	7.38	38.70	174.50	73.70	62.23	7.44
	Q			epm	2.35	2.05	2.70	0.28		1.29	2.86	1.53	1.75	
				%	31.89	27.77	36.53	3.81		17.34	38.45	20.63	23.59	
2		7.59	432	ppm	51.28	28.65	62.00	10.0	7.87	23.22	200.70	80.18	76.59	7.89
	Q			epm	2.56	2.36	2.70	0.26		0.77	3.29	1.67	2.16	
				%	32.53	29.95	34.27	3.25		9.81	41.68	21.15	27.37	
3		7.96	514	ppm	47.17	43.30	80.00	13.0	9.73	27.09	232.10	96.22	90.95	9.28
	Q			epm	2.35	3.56	3.48	0.33		0.90	3.80	2.00	2.56	
				%	24.20	36.61	35.76	3.42		9.73	41.01	21.60	27.65	
4		7.79	663	ppm	92.30	37.38	90.00	5.00	11.72	23.22	184.90	148.20	174.73	11.82
	Q			epm	4.61	3.07	3.91	0.13		0.77	3.03	3.09	4.93	
				%	39.30	26.23	33.39	1.09		6.55	25.64	26.11	41.70	
5		8.05	573	ppm	43.07	11.21	160.0	4.00	10.13	21.42	290.40	39.94	148.40	10.49
	Q			epm	2.15	0.92	6.96	0.10		0.71	4.76	0.83	4.18	
				%	21.22	9.10	68.67	1.01		6.81	45.37	7.93	39.89	
6		7.62	735	ppm	123.0	32.39	90.00	16.0	13.12	30.96	358.0	79.35	184.30	13.75
	Q			epm	6.14	2.66	3.91	0.41		1.03	5.87	1.65	5.20	
				%	46.77	20.30	29.82	3.12		7.51	42.68	12.02	37.80	
7		8.09	1759	ppm	131.2	184.4	230.0	6.00	31.87	39.27	312.10	399.10	612.41	32.00
	Q			epm	6.55	15.17	10.00	0.15		1.31	5.12	8.31	17.27	
				%	20.55	47.59	31.38	0.48		4.09	15.98	25.96	53.96	
8		7.9	2705	ppm	120	330	380	20	50.12	50	277.15	517.4	1150	49.41
	Q			epm	5.99	27.2	16.52	0.51		1.67	4.54	10.77	32.43	
				%	11.99	54.07	33.96	1.0		3.37	9.19	21.8	65.63	
9		7.36	6421	ppm	902.50	137.08	1200.0	20.00	109.00	0.00	79.84	1094.0	3027.0	109.45
	P			epm	45.03	11.27	52.18	0.51		0.00	1.31	22.78	85.36	
				%	41.32	10.34	47.87	0.47		0.00	1.20	20.81	77.99	
10		7.35	19762	ppm	4410	354	2200	46	346.01	0.00	140	682.0	12000	354.89
	P			epm	220.06	29.11	95.66	1.18		0.00	2.29	14.2	338.4	
				%	63.59	8.41	27.64	0.34		0.00	0.64	4.0	95.35	
11		7.66	8186	ppm	494.00	262.19	2050.0	10.00	135.60	0.00	145.20	1659.0	3638.00	139.51
	P			epm	24.65	21.56	89.13	0.26		0.00	2.38	34.54	102.59	
				%	18.18	15.90	65.73	0.19		0.00	1.71	24.76	73.54	
12.	P	7.81	4824	ppm	926.00	162.00	500.00	58.00	82.75	49.98	333.90	1405.0	1555.80	80.26
				epm	46.21	13.32	21.74	1.48		1.67	5.47	29.25	43.87	
				%	55.84	16.10	26.27	1.79		2.08	6.82	36.44	54.66	

Q= Quaternary Aquife P= Paleogene Aquifer

Table 2: Chemical analysis data of pre-treatment and post treatment of brackish groundwater samples using CA&PEG-g-AAc reverse osmosis membrane

Sample & Operation time	TDS (ppm)	unit	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Total cations	CO_3^{--}	HCO_3^{-}	SO_4^{--}	Cl^{-}	Total anions	Salts (%)				
													NaCl	$MgCl_2$	$MgSO_4$	$Mg(HCO_3)_2$	$Ca(HCO_3)_2$
Baneit pre-treatment	2705	ppm	120	330	380	20.0	50.12	50	277.15	517.4	1150	49.41	34	32	21	1	12
		epm	5.99	27.2	16.52	0.51		1.67	4.54	10.77	32.43						
		%	11.99	54.07	33.96	1.0		3.37	9.19	21.8	65.63						
After 5Hr.	2124.7	ppm	71.5	236.4	360	20.0	39.17	35	235.6	280	1004	39.15	41	32	15	4	9
		epm	3.57	19.44	15.65	0.51		1.16	3.86	5.82	28.31						
		%	9.11	49.63	39.96	1.3		2.96	9.85	14.86	72.31						
After 16hr.	1856.6	ppm	61.43	197.9	340	17.0	34.56	27.26	218.2	230	874	33.92	44	29	14	4	9
		epm	3.07	16.28	14.78	0.43		0.91	3.58	4.79	24.65						
		%	8.87	47.09	42.78	1.26		2.68	10.54	14.12	72.66						
After 24 hr.	1682.1	ppm	48.21	170.4	330	15.0	31.14	27	187.1	210	791	30.54	47	26	14	5	8
		epm	2.4	14.01	14.35	0.38		0.799	3.07	4.37	22.31						
		%	7.7	44.99	46.08	1.22		2.61	10.05	14.3	73.05						

Table 3: Chemical analysis data of pre-treatment and post treatment of highly saline groundwater samples using CA&PEG-g-AAc reverse osmosis membrane

Sample& operation time	TDS (ppm)	unit	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Total cations	CO_3^{--}	HCO_3^{-}	SO_4^{--}	Cl^{-}	Total anions	Salts (%) NaCl	$MgCl_2$	$CaCl_2$	$CaSO_4$	$Ca(HCO_3)_2$
Observation pre-treatment	19762	ppm	4410	354	2200	46	346.01	0.0	140	682.0	12000	354.89	28	9	58	4	1
		epm	220.06	29.11	95.66	1.18		0.0	2.29	14.2	338.4						
		%	63.59	8.41	27.64	0.34		0.0	0.64	4.0	95.35						
After 5 hr.	17076	ppm	3836	310.4	2000	42.0	304.98	0.0	120	450.0	10378.	303.99	29	8	59	3	1
		epm	191.42	25.53	86.96	1.07		0.0	1.96	9.37	292.66						
		%	62.76	8.37	28.51	0.35		0.0	0.64	3.08	96.27						
After 8 hr.	15223	ppm	3400	236.4	1900	37.0	272.66	0.0	100	400	9200	269.4	31	7	59	3	1
		epm	169.66	19.44	82.61	0.95		0.0	1.69	8.33	259.44						
		%	62.22	7.13	30.29	0.34		0.0	0.608	3.09	96.3						
After 16 hr.	14076	ppm	3100	187.1	1800	33.0	249.18	0.0	92.55	350.0	8560	250.19	32	6	58	3	1
		epm	154.69	15.39	78.26	0.84		0.0	1.51	7.29	241.39						
		%	62.02	6.17	31.4	0.33		0.0	0.603	2.91	96.48						
After 24 hr.	13041	ppm	2900	153.8	1750	13.0	233.78	0.0	80	325.0	7860	229.72	33	5	58	3	1
		epm	144.71	12.65	76.09	0.33		0.0	1.31	6.76	221.65						
		%	61.9	5.41	32.54	0.14		0.0	0.57	2.94	96.48						

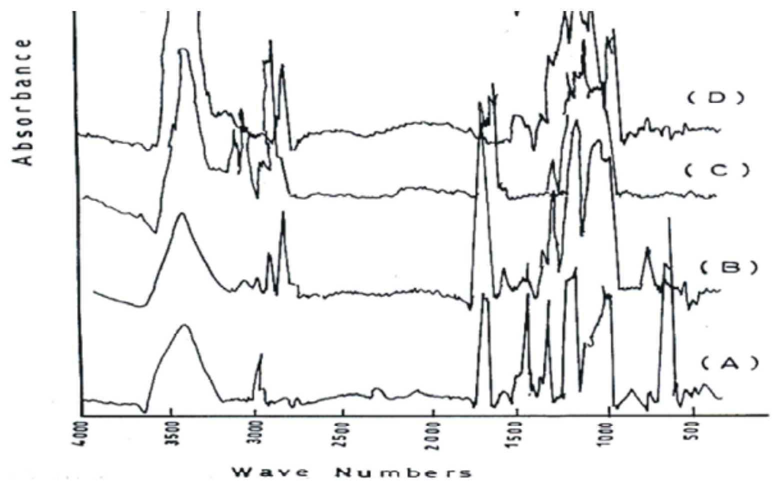

Fig. 3a: FT-IR Spectra for (A) CA, (B) un-grafted CA&PEG and AAc grafted CA&PEG membrane Using radiation technique (C) and chemical initiation technique (D)

that restricts the use of the groundwater in the studied area is the high salinity. For this reason, many trials have been made to synthesize a variety of reverse osmosis membranes that can be used in desalination of saline water [7, 8].

Cellulose acetate (CA) was selected as polymer substrates and modified by blending with polyethylene glycol (PEG) and grafting with acrylic acid (AAc) by dry casting method using two different initiation techniques (radiation and chemically initiated processes). The synthesis of reverse osmosis membranes, Copolymer from (CA&PEG)-g-AAc, their characterization and application in desalination processes were studied.

The characterization of the prepared membranes was carried out by evaluating the swelling behavior, mechanical properties (tensile strength and elongation %), thermal stability, FT-IR spectroscopy X-ray diffraction pattern as well as morphological changes by scanning electron microscope (Fig. 3a, b and c).

The RO membranes acquiring the highest values of characteristics were selected as reverse osmosis membranes for desalination of saline water. The effects of the different variables affect reverse osmosis parameters (salt rejection and water flux) were studied. These variables included solvent evaporation (evaporation time and evaporation temperature), PEG addition, chemical treatment, membrane thickness, monomer/polymer ratio, applied pressure, operation time and feed concentration.

Application of Reverse Osmosis Membranes for Desalination of Groundwater: Desalination of brackish and saline groundwater samples collected from

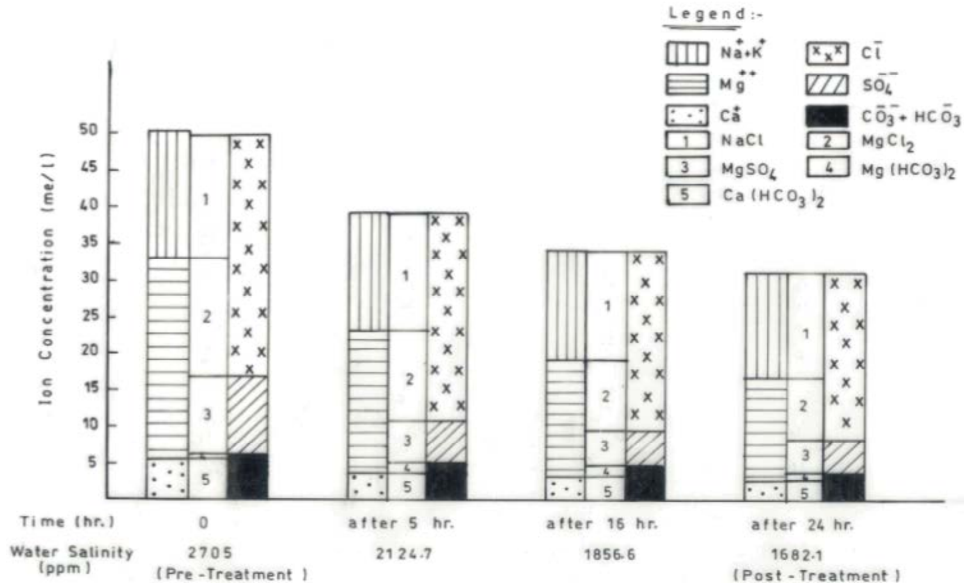

Fig. 4: Graphical presentation of ions distribution of the pre-treatment and post treatment for brackish water desalination process at different operation times using the selected desired RO membrane

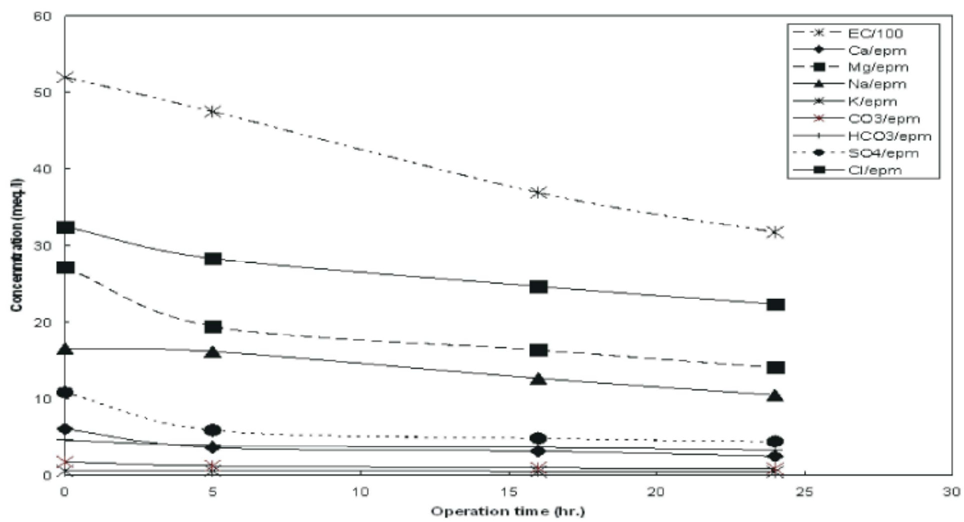

Fig. 5: Salinity and ionic concentration permeated as a function of operation time during desalination of brackish groundwater sample, using the selected desired membrane

Wadi El-Assiuti area was performed. Two groundwater samples, brackish and saline, from Quaternary Deposit and Paleogene Carbonate aquifers were used. The changes in concentrations of major cations and anions were studied by measuring these concentrations before, during and after the desalination process.

Desalination of Brackish Groundwater Sample from the Quaternary Deposits Aquifer System: The feed brackish groundwater (TDS=2705 ppm) and slightly alkaline pH (7.9) from well No.8 is pumped into a closed vessel in the reverse osmosis unit. The results show that the total mineralization (water salinity) as well as the ionic composition of the groundwater decrease gradually as a function of desalination operation time. By using the best desired selected suitable membrane, the total dissolved solids of post treatment water became 2124, 1856 and 1682ppm at operation times of 5, 16 and 24 hr., respectively (Fig. 4, 5 and Table 2).

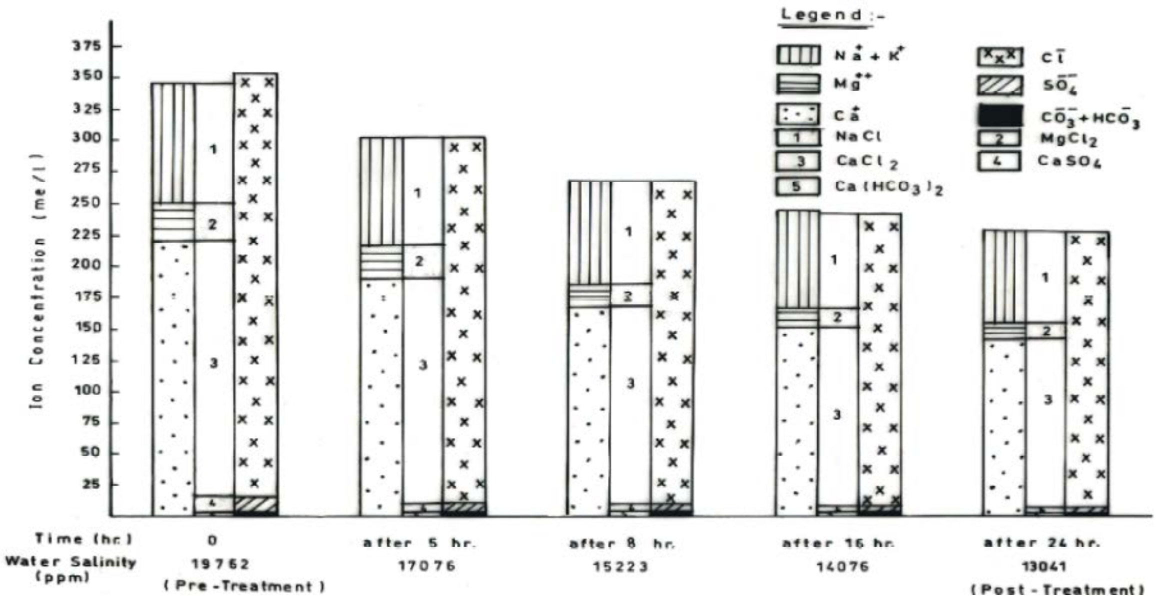

Fig. 6: Graphical presentation of ions distribution of the pre-treatment and post treatment for highly saline water desalination process for different operation times using the selected RO membrane

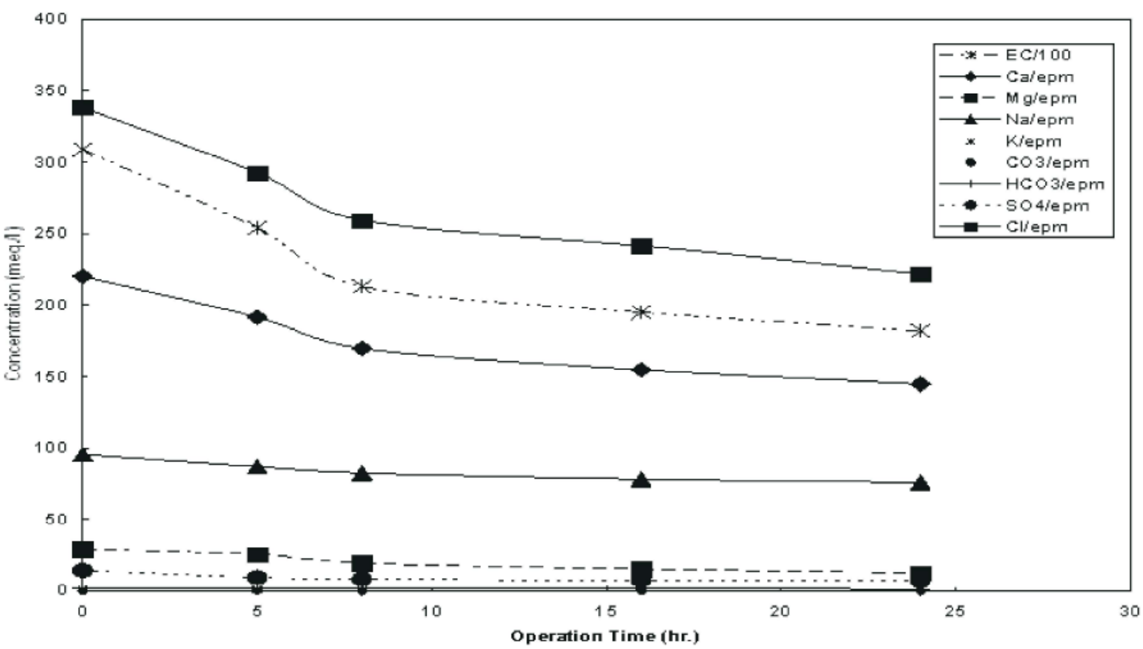

Fig. 7: Salinity and ionic concentration permeated as a function of operation time during desalination of highly saline groundwater sample, using the selected membrane

Desalination of Highly Saline Groundwater Sample from the Paleogene Carbonate Aquifer System: The feed of highly saline groundwater (TDS=19762 ppm) of slightly alkaline pH (7.4) from well No.10 is pumped into a closed vessel in the reverse osmosis unit. The results show that the total mineralization (water salinity) as well as the ionic composition of the groundwater decrease gradually as a function of desalination operation time. By using the selected membrane, the values of total dissolved solids of post treatment water become 17076, 15223, 14076 and 13041ppm at operation times of 5, 8, 16 and 24 hrs., respectively (Fig. 6, 7 and Table 3).

CONCLUSIONS

From the geochemical study of the groundwater of the different aquifers in the study area, it is clear that most groundwater suffers from the problem of high salinity that is unsuitable for the population drinking or irrigation. So many trials to overcome such problems are essentially needed. This can possibly be done through synthesis variety of reverse osmosis membranes and evaluate their applications in the desalination of brackish and saline water samples. In the current study, the membranes were synthesized from cheap polymers to minimize the cost of a cubic meter of desalted water.

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