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Geoenvironmental Impact Assessment of El-salam Canal on the Surrounding Soil and Groundwater Flow Regime, NorthWestern Sinai, Egypt

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ABSTRACT

El-Salam Canal is one of the major irrigation projects being implemented in Northern Sinai in 1998. About 400,000 feddans are reclaimed on the eastern side of Suez Canal by this project. Water supply of El-Salam canal has been driven from Damietta branch of the river Nile and two agricultural drains, located to the east of Nile Delta. Land sat TM data are used to examine the impact of El-Salam canal on El-Tina Plain. The optimum three-band combinations were selected to monitor land-use changes for the periods of 1984–2003 and 2003–2014.Water quality is determined based on chemical, physical, biological and isotopic contents to provide a full description of the various constituents that may affect the water-use and recharge history of groundwater. Data integration indicates that the area is under threat from four types of hazards including; Water logging; soil salinization; water pollution; and sea shore erosion of Mediterranean coast. The results display that, the wetlands area had increased from25km^2 (2.4%) in 1984 to 180km^2 (18%)in 2014 along El-Tina Plain. Urbanized and cultivated areas were significant in 2014, covering about 89 km^2. Several factors control the land-cover changes, including groundwater level rise, inadequate drainage distribution and increasing of fish farms. Soil properties strongly support the high susceptibility to water logging and soil salinization due to the duplex soil texture along El-Tina Plain.

Key words: El-Salam Canal**,** El-Tina Plain, groundwater, shoreline erosion, soil salinization, waterlogging.

INTRODUCTION

Statement of the problem

The study area occupies the eastern side of Suez Canal Navigation route, between El-GadyPass to the south and El-Tina plain to the north. It lies between latitudes 30° 30' - 31°15' N, and longitudes 32°:15' – 32°:30' E (Fig. 1). Within the framework of the Egyptian governmental efforts to develop the desert areas and new communities, great efforts are being paid to convert portion of the new communities in North Sinai into productive lands, especially within the distinct increase in population, agricultural, industrial development and consequent water needs. El-Salam Canal is the main water supply of the comprehensive land reclamation projects which are being implemented in Northern Sinai. About 400,000 feddans are being developed at the eastern side of Suez Canal by this new project. Benefiting from some waters of Alsro Al-Asphal and Bahr Hadous agricultural drains along the eastern Nile Delta flank, amount of 10 million m^3/d of drain water are being used in irrigation through mixing them with the fresh Nile water at a ratio of 1:1. The canal runs along North Sinai Governorate through a main tunnel beneath Suez Canal Navigation Route to El-Tina Plain and furthermore to south of El-Arish City (Fig. 2).

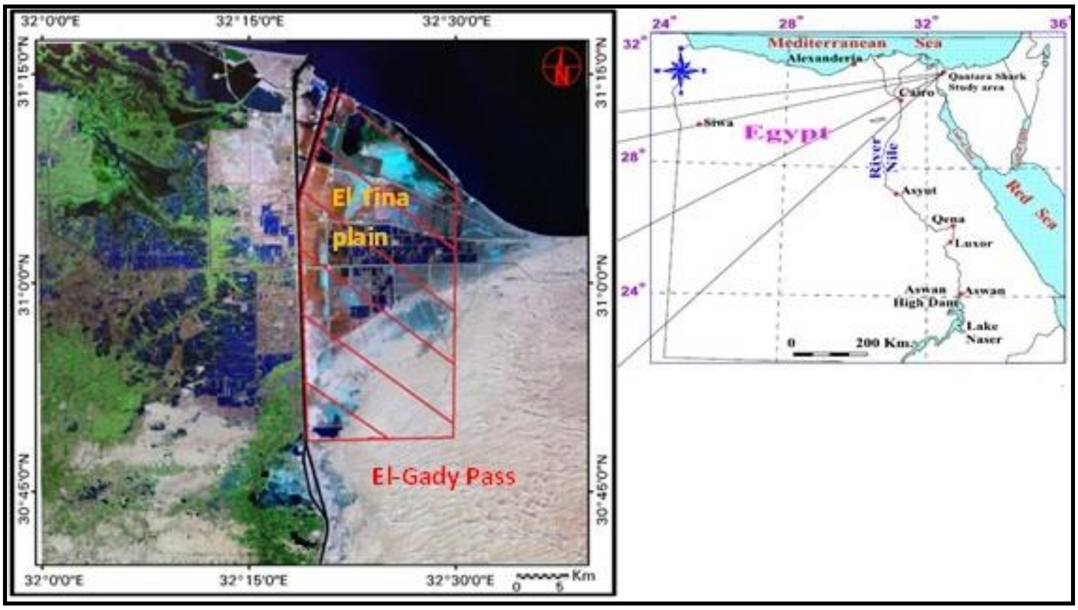

Figure (1): Location map of the study area.

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Figure (2): El-Salam Canal Project area.

Waterlogging and soil salinization are the prevailing forms of land degradation in the low lying cultivated lands of the study area (Fig. 3) that is predicted to become a serious environmental problem in the next few decades (El Sheikh *et al*., 2013). The absence of the role of geological determinants in the strategy of land reclamation and developments are the most responsible causes of the problem. Erosion of the sea shoreline is another challenge along the coastal zone. Erosion of the shoreline is attributed to the erosive action of sea waves and currents, the loss of the suspended load along the shoreline and the decrease of the energy of the transporting river water flow current strengthen the erosive effects of the sea water.

The area of study represented by old deltaic plain of the ancient Pellusic Nile branch that has been traced on a deltaic plain east of the Suez canal between El-Baqar canal and Tell El-Farama (ancient Pellusium) with two markings distributaries branched northward (Senah *et al*., 1975).

The coastal lagoons, prevailed along the coastal zone were probably cut off from the sea and partly filled by the deposits of clastics in sheltered embayment of such old Nile branches (Hamama, 1978).Erosion processes have been detected on all the delta coastal plain except some limited areas. Rosetta and Damietta promontories seem to be the most eroded areas (Klemas and Abdel Kader, 1982).

Figure (3): Different forms of land degradation due to waterlogging at the study area.

The groundwater potentialities in the north-western Sinai are more limited than in the north-eastern area. The former is occupied by sand dunes which constitute the main aquifer and the water was existed at depth varying between 1m and 7m from the ground surface, where the groundwater exists as a thin layer above the main saline water (El-Shazly *et al*., 1975).Therefore, this precious water resource is highly venerable to pollution. The area of study could be subdivided into two transversal regions. In the northern region, the ground water is mostly saline unsatisfactory for irrigation and its potentiometric surface lies at higher level than the ground surface. In the southern region, the groundwater quality is good satisfactory for irrigation and its free surface lie at relatively lower levels. The groundwater is recharged from the fresh surface water canals and irrigation water return flow.

The study area is threatened by the following geo-environmental hazards (Figs. 3-5):

1- Land degradation due to mis-land use planning strategy.
2- Land subsidence.
3- Loss of fertile soil and great amount of water due to waterlogging and high evaporation rate.
4- Risky levels of water pollution.

Aims and objectives

The main objectives of the present study are to fingerprint the impact of new land development activities including; construction of El-Salam Canal and increasing irrigation practices and to assess, manage and protect the groundwater quality and potentiality of El-Salam Canal project area.

MATERIALS AND METHODS

The methodological approach of the present work is built on the basis of following up the footprints of the impacts of El-Salam Canal project activities since the canal digging on the surrounding environs at 1998, using integral hydro geological, remote sensing and shallow subsurface drilling approaches. The problem is managed using mathematical modelling techniques. Hydro chemical and environmental isotope analyses, in conjunction with field observations and other previously obtained data sets, were used to “fingerprint” different water types, and decipher the nature of physicochemical processes, origin, recharge sources and history of groundwater flow regime. Water sampling was carried out to measure major ion contents(in 22 groundwater samples and 14 surface water samples from drains, El-Salam canal and its distributaries), trace and heavy metal contents (in 12 samples) and environmental isotopic content (in 4 groundwater samples). The water analyses were done in the hydro geological laboratory of Geology Department, Suez Canal University for the major ion constituent following the instructions and standard methods of APHA (1971).Trace metals and environmental isotopes analyses were carried out in the laboratories of Tubingen University, Germany (Institutes of Geography and Mineralogy). To determine the interaction between surface water and shallow groundwater resources, seepage measurements along El-Salam canal and its distributaries and drains were carried out by calculating all elements of inflow and outflow at 7 sections for El-Sheikh Gaber and South El-Qantarah main canals (distributaries of El-Salam Canal) and Balozah drain using a spiral current meter.

Remote sensing data processing and interpretation have been done using the Thematic Mapper Images (30 m resolution) which acquired on August 1984, July 2000 and August 2014 (Path 176, Row 38). Extracted data were used to compare the shoreline positions during two different erode (1984–2000 and 2003–2014). The first image, 1984 was from the Thematic Mapper on Landsat 5, the second image, 2000 was collected from the enhanced Thematic Mapper (ETM) on Landsat 7, while the third one, 2014 was from the landsat 8. Geometric correction of the most recent image,2014 formed part of the current research project. These data were registered to the corrected Nile Delta images for the year 2000 (Kaiser, 2004 and 2009) and further rectified to ground control points (GCPs) measured during the field investigation of the present research.

RESULTS

Physiography and geologic setting

The area is mainly characterized by low altitude of about 1.0 m above sea level, whereas the southern and eastern parts are relatively of higher relief ranging from a few meters to the North and rise up to more than 45m southward above sea level. Few localities have very low relief reaching -1 m below sea level where it is covered by sabkha deposits. The northern low lands are covered by salt marshes and sabkhas while, the southern lands are covered by sand sheets and sand dunes (Fig. 4).Ridges of low altitude between 0.5 and 2.0 m are common in the northern shoreline.

The study areawas an integral part of the ancient Nile Delta system (Stanley,1988). It has a concave shoreline configuration of about 39 km long and 818 km^2 surface area. The El-Tina Plain (core of the study area) is subsiding at a rate of about 0.5 cm/year. It is estimated that the sea level could rise 50 cm by the year 2100 (Stanley, opt. cit.). The amount of new sediment reaching the plain through the Nile River has been greatly reduced over the last 16 decades following the construction of the Suez Canal Navigation Route. The study area can be divided into six physiographic features including; the sandy shore, the coastal plain, the marginal lagoon, the old Nile floods plain, the sand dune belt and the sabkhas. Geologically, it is completely covered by Holocene and Pleistocene sediments of littoral, alluvial and aeolian origin which show variations in their texture and composition ranging from unconsolidated sands to salinized silt and clay of chemical and biochemical origins (Dewidar&Frihy, 2003).

The southern part of the El-Tina plain is a part of the Nile flood plain and is composed of silty clay intercalated with salts, evaporites and sands, forming a duplex soil structure along El-Tina Plain area in the western part.

Moving eastward, sediment composition shifts to silty clay and clayey silt covered with a salt crust (Deiab, 1998). The Mediterranean coast of Sinai is influenced by tectonic features such as the Pellusium line and coastal hinge fault (Neev et al., 1982).

El Tina Plain and its vicinities are occupied by a strip of the Egyptian Mediterranean coast zone to the east of Port Said. The acting dynamic processes in the study area include the sea elements (waves, currents, and tides), wind and occasional rainfall. Quaternary sediments, covering the study area, controls to some extent the rate of land sculpturing (degradation and a gradation processes).

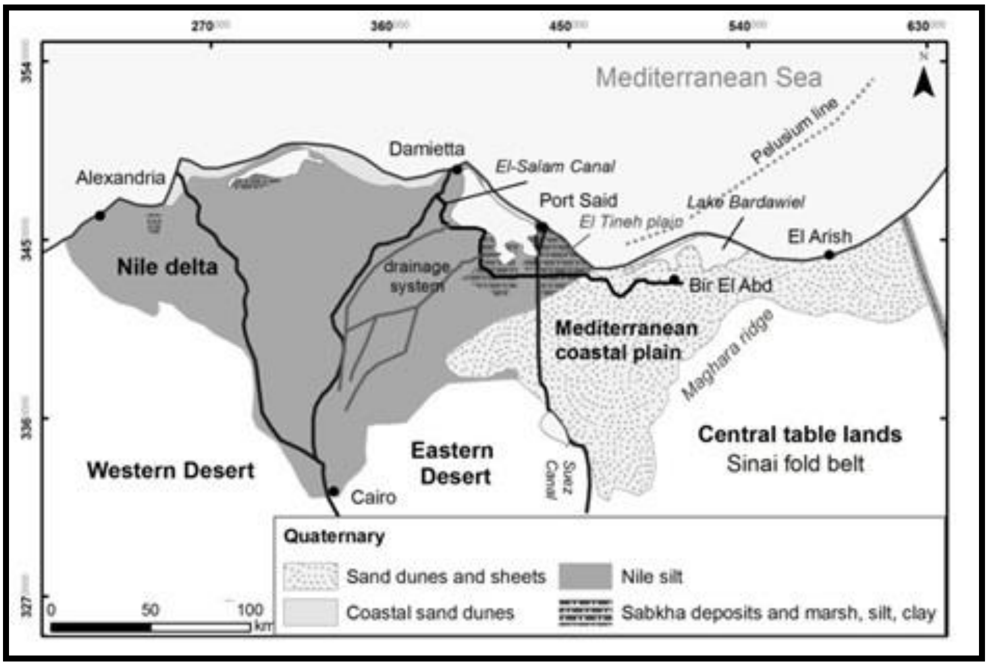

Figure (4): Geomorphological and geological map of El-Salam Canal area (CONOCO, 1987 and Stanley and Warne 1998).

Hydrogeologic setting

Groundwater occurrences

In the study area, three types of aquifers could be identified which are:

1- The lower aquifer is semi –confined, 80m thick of gravelly sands composition, corresponding to the Early Pleistocene succession occupying the southern sector of the study area and forming the main water-bearing formation beneath the intermediate aquifer at the northern sector; The intermediate aquifer is semi –confined with 15m thick and corresponding to the late Pleistocene, overlying the main aquifer especially, along the northern sector.

2- The upper low permeable aquifer is considered unconfined with thickness about 33m and corresponding to the late Pleistocene-Holocene covering El-Tina Plain area. It sometimes constitutes aquitard layer along the central core of the plain.

3- The northern sector crosses through low land areas (+,-1masl.).It is bounded by old deltaic loamy sand deposits, which were deposited in an extended morpho-tectonic basin. Such deposits contain brackish to saline groundwater. Water salinity increases with depth reflecting the occurrence of two groundwater horizons. The deeper one is most probably fossil water that may be affected by the Plio-Pleistocene fluvio-marine wet periods with long resident time. While the less saline shallow groundwater floats over the aforementioned brackish deeper one due to density variations and probably recent fresh water recharge from El-Salam canal irrigation system.

Groundwater Flow

A number of 30 boreholes were surveyed during the present work (Table 1), from which, a water table map has been constructed (Fig. 5). Data collection and field measurements indicate that, the sources of recharge to the shallow aquifer in the study area are mostly attributed to the continuous seepage from El-Salam Canal water and from returned flow water. Seepage from El-Salam Canal is clearly noted as water bonds and wetlands around the canal course. Returned flow water due to irrigation practices is noted as groundwater mounds along the upland irrigated areas to the East and South of the study area. General hydraulic gradient towards the Suez Canal to the western and north-western parts are observed. Because of the above mentioned conditions, waterlogging problem is created especially at the irrigated lands, fishing farming area sand the local depressions. This logged water increases water salinity due to the high evaporation and low soil permeability therefore; they greatly affect the shallow groundwater flow regime of the study area and help loosing huge amount of water via evaporation.

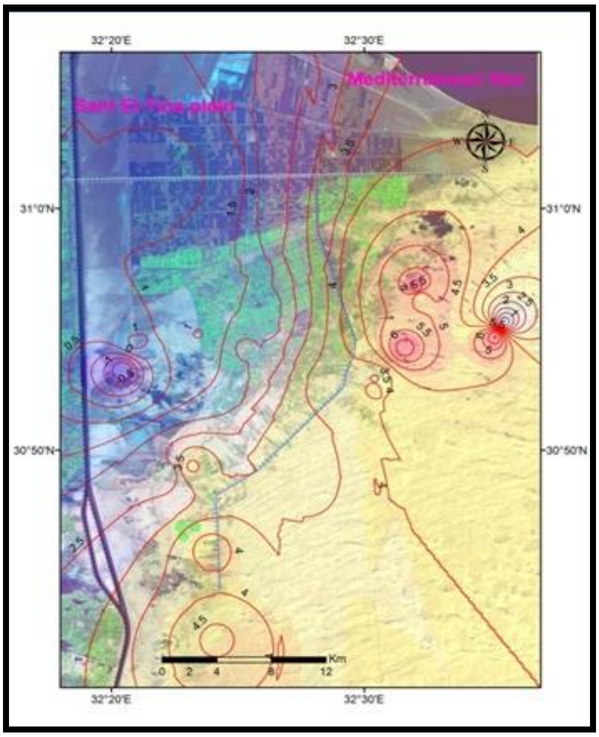

Figure (5): Groundwater flow directions of the shallow aquifer.

Seepage measurements along the canals and drains were carried out for El-Sheikh Gaber and South El-Qantarah main canals and Balozah drain (Fig.6). The volume rates of discharge were obtained directly by the velocity – area method using a spiral current meter. The obtained results show that, both of El-Sheikh Gaber and South of El-Qantara Canals are influent streams. The average water loss along 20 km of El-Sheikh Gaber amounts average value of 1,393,300 m^3/day with a seepage rate of 0.9 m/day (Table, 1). While, along South El-Qantara Canal the seepage loss amounts 337,147 m^3/day with an average rate of 0.54 m/d. The amount of drained water by Balozah drain to the Suez Canal is estimated as 1,389,690m^3/day. High seepage rate along the measured sections of El-Sheikh Gaber canal could be attributed to the feeding of the surrounding wetlands and surface water bonds, which prevailed along this section, with huge amount of water that is continuously subjected to evaporation. The estimated loss from these wetlands by evaporation are averaged as 394.2 million m^3/year(1,080,000 m^3/day) considering that the average evaporation rate is 6 mm/day and the wetlands area is about 180 km^2 as inferred from the remote sensing data. It could be concluded that a huge amount of water is lost through this part of the study area by the seepage from the irrigation canals and consequent evaporation from the prevailed wetlands. The average amount of water losses by discharge of Balozah drain to the Suez Canal and evaporation to the atmosphere respectively amounts together about 2,469,690 m^3/day of the Nile water supply to the area without any benefits.

Seepage and water loss

Table (1): Summary for the obtained results of seepage measurements in the study area.

Section name	length	Upstream discharge			Contribution to irrigation	Downstream discharge			Loss	Seepage rate
	km	A	V	Q	m3/d	A	V	Q	m3/d	m/d
El-Sheikh Gaber Canal	20	241	20,399	4,920000	2,720000	43.5	18,545	806,720	1,393,300	0.9
South Qantara Canal	19	20,75	66,220	1,370,750	100,369	17.5	73,828	1,033,603	337,147	0.54
Balozah Drain	Down stream					23.17	59,978	1,389,690	Loss to Suez Canal	

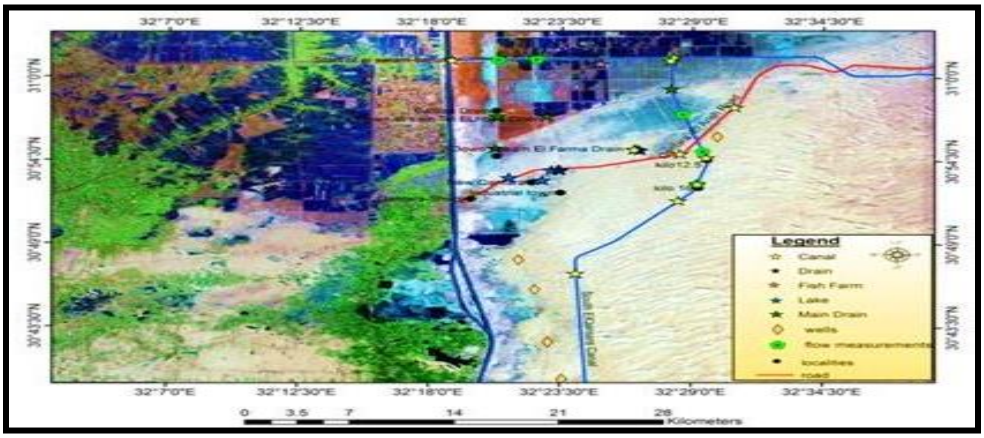

Figure (6): Locations of water sampling and flow measurements in the study area.

Hydraulic properties

Hydraulic conductivity was collected and measured for a number of 22 boreholes distributed in the study area (Fig. 6 &Table, 2). Some of the collected data are referenced to the National Research Institute of Water Resources, RIWR, (2013) and a number of additional measurements are carried out during the present work for 14 wells and auger holes. The collected samples have been measured in the Hydrogeology Laboratory, Suez Canal University using constant head parameter. The measured hydraulic conductivity of the water-bearing formation varies between 0.4 – 3.9 m/day. The low values represent the salty fine to loamy sands, observed in the middle area, while the high values represent the southern sandy aquifer.

Table (2): Collected data of the borehole drilled in the study area.

Borehole No.	TD (m)	Lat. N	Long. E	TDS (mg/l)	G.L (masl)	DW (m)	WT (masl)	K (m/d)
H1	6.0	30.9116	32.5861	9067	8.64	2.10	6.54	2.18
H2	5.0	30.8783	32.5061	1612	5.83	1.45	4.38	3.22
H4	4.3	30.8372	32.4566	4826	3.81	0.50	3.31	1.85
H8	23.5	30.8761	32.4763	1144	12.02	8.25	3.77	5.7
H11	30	30.9038	32.5264	6173	10.88	4.60	6.28	2.65
H12	3.0	30.8888	32.3410	11056	0.65	0.80	-1.45	0.75
H13	5.5	30.9394	32.5366	4492	5.80	1.30	4.50	1.25
H16	5.0	31.0156	32.3640	1559	2.65	2.10	0.55	2.35
W45	105	30.8222	32.3866	10408	24.10	20.50	3.60	6.22
W51	35	30.7652	32.3986	5722	16.20	12.00	4.20	8.45
W6	20	30.7030	32.4027	6074	26.80	22.20	4.60	12.23
W7	7.8	30.9033	32.4216	4520	4.65	2.50	2.15	3.75
P1	2.5	30.91611	32.34928	5700	1.75	0.80	0.95	1.12
P2	1.2	30.91339	32.39036	5200	1.65	0.70	0.95	2.3
P3*	12	30.90789	32.34973	4690	1.48	0.33	1.15	0.62
P4*	15	30.9216	32.59226	10980	1.23	0.55	0.68	2.34
P5*	18	30.92118	32.38167	3400	3.68	2.63	1.25	1.8
P6*	17	30.94512	32.53454	3200	9.05	2.65	6.40	3.4
P7*	12	30.90335	32.38887	4500	1.90	0.70	1.20	1.2
P8*	15	30.88154	32.50654	3400	6.30	3.10	3.20	3.6
P9*	20	30.92765	32.42921	5600	2.25	0.75	1.50	0.4
P10*	12	30.81665	32.36987	3500	5.81	3.60	2.21	3.9

Remote sensing analyses

Supervised classification (Fig. 7) for each date was conducted using field observations collected from more than 25 ground checkpoints and digital topographic maps of the study area. Five geomorphologic classes were extracted from 1984, 2000and 2014 images using image classification. El-Salam Canal Development Projects were responsible for the increase waterlogging and urban land use surface area in 2000 and 2014 after the completion of canal digging process. The surface area of cultivated land also increased due to land reclamation. Water logging and wetlands surface areas and sabkhas and salt crust surface areas increased as a result of seepage and irrigation practices on the newly developed lands. This increase in wetland habitats is caused primarily by human activities including the creation of fish farms, groundwater level rises and seepage from the irrigation system. Image data obtained were integrated with data collected from topographic and morphologic maps and field observations in order to quantify the environmental changes on the El-Tina plain following the infrastructure development during 1984–2000 and 2010. The impact of the East Port Said harbor on the landward displacement of the shoreline was evaluated and assessed using vector data analyzed by image segmentation and region growing techniques. The rate of coastal erosion increased from -13 m/year during 1984–2000 to -15 m/year during 2000–2014, following the construction of the harbour. The observed land use/land cover changes were caused by several factors. The study area has been subjected to intensive local planning and development projects such as construction of the El-Salam Canal, the creation of the East Port Said harbour, an increase in industrialization, fish farms and land reclamation. From 1926 to 1987, the sea level rose 16 cm (average rate of 2.6 mm/year) and it is likely that sea level will continue to rise by another 44.2 cm by 2100

(Frihy, 1992).In addition, the headland feature of the El-Tina plain coastline has caused extensive erosion on the down drift site of the East Port Said harbour.

Multispectral image classification analyses indicate that the southern part of the El-Tina plain has seen formerly undeveloped tracts converted to agriculture. Given the expansion of agricultural production it is not surprising that both urban and designed cultivated land areas increased significantly as well as in contiguous way, wetlands increased based on 1984 and 2014 data from 25km^2 (2.4%) at to 180km^2 (18%) respectively. The area of land covered by a salt crust decreased from 487km^2 in 1984 to about 137.4 km^2 in 2014 (Fig. 7).

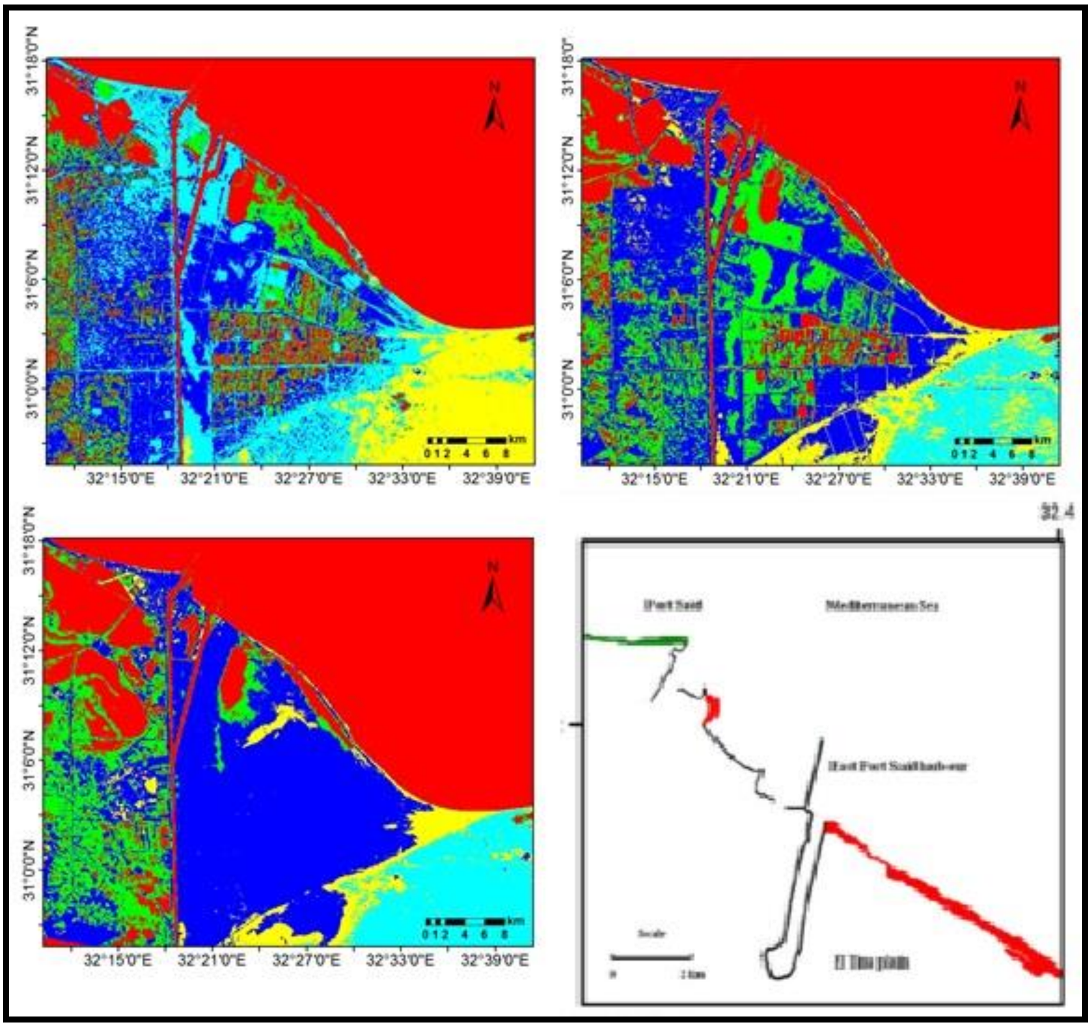

Figure (7): Supervised classification of satellite images for 1984, 2000 and 2014 in the El-Tina plain. Surface water (red), cultivated and wetland areas (green), salt crust (blue), Quaternary and Playa deposits (yellow) and fluviatile and lacustrine deposits (pale blue).

DISSCUSION

Water quality assessment

Hydrogeochemical Characteristics of El-Salam Canal water

The obtained resultsof hydrochemical analyses (Table, 3) reveal general increment trend of the total dissolved solids (TDS) along El-Salam Canal from upstream towards the downstream.TDS varies from 260 ppm at the head water points at Dammita Nile branch to 870 ppm at the most distal downstream.At mixing points of El-Sarow and Bahr Hadous Drain, sudden increase of Na and Cl isclearly observed (Fig. 8). The most dominant ion order is Ca > Mg and HCO_3>C1>SO_4 (Fig., 9). Toward the downstream, Cl replaces HCO_3 and the dominant ion order changed to be Na>Ca> Mg and C1>HCO_3> SO_4as a result of a probable ion exchange process.

The sodium absorption ratio, SAR and nutrients (nitrates and phosphates), are detected in most of the examined water of El-Salam Canal by high concentrations (Table 3). Their concentration levels are much higher than Nile water due to mixing of the canal water with the agricultural drain water (samples, 7&12). High nitrate concentrations in drinking water may negatively affect body development, particularly the nervous and the heart systems of the children (Bouwer, 1978). The results of trace elements: Pb, Cd, Fe, and Zn (Table 4) indicate that a considerable number of the examined samples have higher contents than the maximum desirable standard for drinking water that recommended by the EPA (1975) and the Egyptian Higher Committee of Water - EHCW (1995). This could be attributed to the mixing of drain waters which constitute the higher concentration values. The results of microbiological analyses (Table 3) indicate that most of examined samples are rich in *faecal* coli form especially those collected from the mixing points with El-Sarow and Bahr Hadouse drains. The highest count (1258 MPN/100ml) was recorded in Bahr Hadouse drain. The high content of this type of bacteria in water are attributed to the enrichment of water with easily assembled organic substances(Geoffay and Vial, 1975) derived essentially from discharged organic matters from the surrounding arable areas and sewage effluent to the drains waters. This means that there is a high probability for human infection by diarrhea, dysentery, cholera, and hepatitis, especially those people who swimming or washing their closes and cooking dishes in the canal water as observed in the study area.

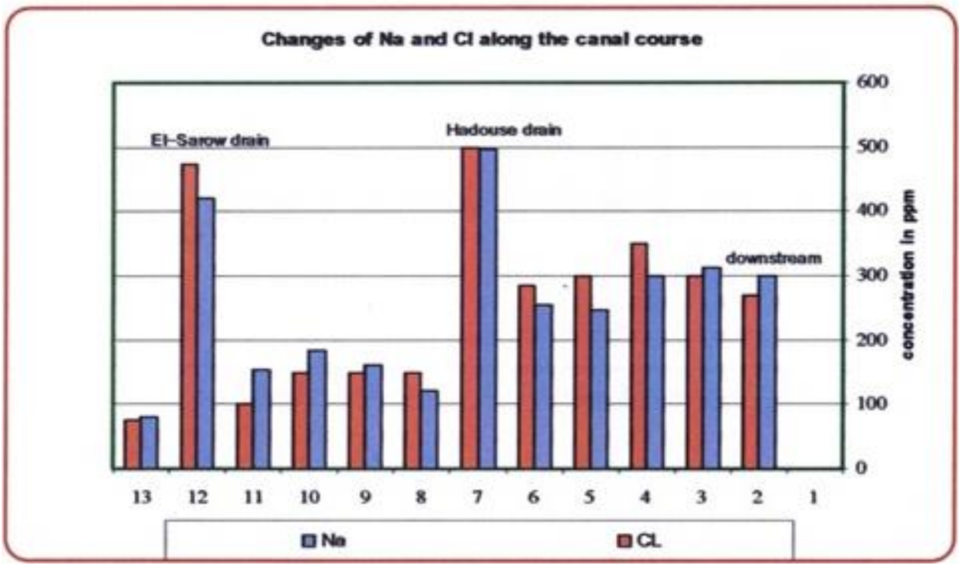

Figure (8): Sudden increase of Na and Cl at mixing points of El-Sarow and Bahr Hadous Drains**.**

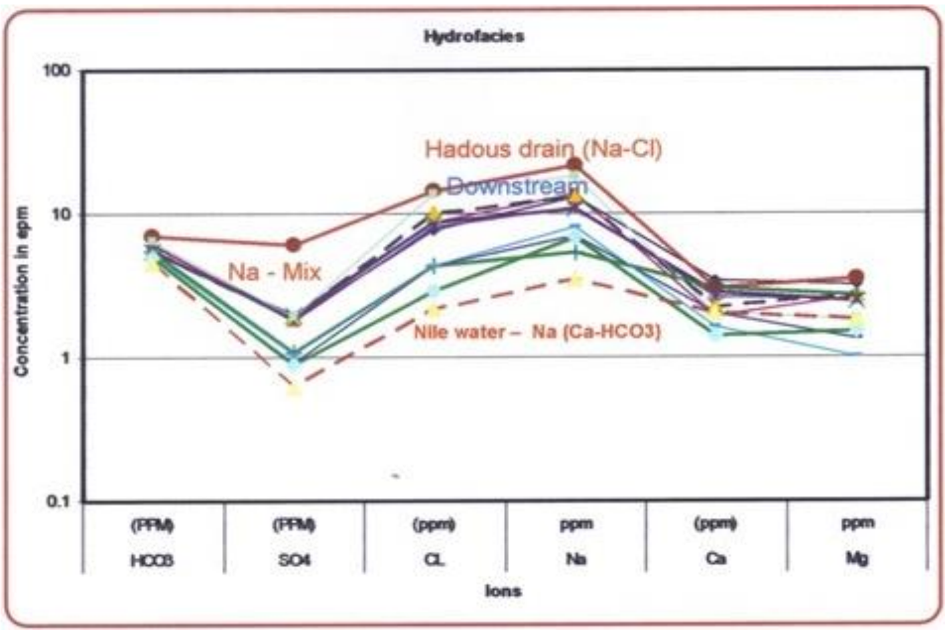

Figure (9): Hydro chemical faces of El-Salam Canal water.

Table (3): Results of hydrochemical analyses of El-Salam Canal water.

No.	TDS (mg/l)	TH (mg/l)	Cl (mg/l)	HCO3 (mg/l)	SO4 (mg/l)	Mg (mg/l)	Ca (mg/l)	Na (mg/l)	PO4 (mg/l)	NO3 (mg/l)	Fecal coliform	SAR %
1	260	200	74.97	274.5	30	22	40	80	1	2	278	2.50
2	920	300	474.9	396.5	91	22	40	422		7	1356	5.81
3	330	200	99.96	305	43	18	28	155	2.5	5	1030	6.81
4	450	20	150	317.2	50	12	32	184	2	4.5	897	6.89
5	440	180	150	305	44	16	40	161	3	5	763	5.33
6	440	230	150	335.5	52	32	60	122	3	6	811	3.11
7	1300	450	499.8	427	290	42	60	496	7	12	1432	12.20
8	760	300	284.9	378.2	85	30	52	255	4	9	1140	6.84
9	740	300	299.9	335.5	95	29	56	246	3.5	9	945	6.40
10	720	300	349.9	335.5	90	32	44	299	3	7	879	8.48
11	760	260	299.9	366	90	31	38	312	2.5	5.5	897	10.91
12	870	300	269.9	335.5	90	38	68	300	2	6	932	9.7
D1	17650	7680	9052	78	2143	522	764	5189	3.2	5.3	2376	5.47
D2	6687	2250	2688	222	1109	165	152	1912	2.6	4.5	1875	2.4

Note: TH: total hardness, TDS = total dissolved solids, SAR = sodium absorption ratio, D1 = Balozah drain, D2 = Faramah drain.

Table (4): Results of trace metal analyses of El-Salam Canal and groundwater in the study area.

Sample No.	Process	Cd	AI	CO	Cr	Mn	Fe	Pb	Zn	Sr	Th
		mg/l									
P1	mixing	0.002	0.004	< .002	0.002	0.003	0.007	0.002	0.009	0.675	nd
P2	mixing	0.002	0.003	<0.002	0.001	0.003	0.006	0.002	0.006	0.540	nd
P3	Hadous Drain	0.005	0.175	0.003	0.003	0.004	0.008	0.003	0.012	0.825	nd
P4	mixing	0.002	0.027	<0.002	0.001	0.003	0.004	0.001	0.005	0.426	nd
P5	mixing	<0.002	0.021	< .002	0.001	0.002	0.003	0.001	0.037	0.211	nd
P6	El-Sarow Drain	0.003	0.042	0.002	0.003	0.004	0.005	0.002	0.105	0.712	nd
P7	Nile water	<0.002	0.023	<0.002	0.001	0.003	0.002	0.001	0.034	0.065	nd
P8	Damitta inlet	<0.002	0.022	<0.002	0.001	0.002	0.002	0.001	0.004	0.054	nd
W6	groundwater	<0.002	0.034	<0.002	0.021	0.001	0.001	< .001	0.005	1.329	0.009
W5	groundwater	<0.002	0.028	<0.002	0.031	0.001	0.015	< .001	0.898	9.769	0.026
W44	groundwater	<0.002	0.045	<0.002	0.019	0.003	0.001	<0.001	0.019	6.118	0.016

nd = not detected.

Hydro geochemical characteristics of groundwater

The groundwater potentialities in the northern sector are more limited than in the southern and southeastern fringes of El-Tina Plain area. The former is occupied by salty loamy sands and sand dunes which constitute the main aquifer and the water was existed at depths varying between 1m and 7m from the surface, where the groundwater exists as a thin layer above the main saline water body. Therefore, this precious water resource is highly venerable to pollution and salinization. The area of study could be subdivided into two transversal regions. In the northern region, the ground water is mostly saline and unsatisfactory for irrigation. Total dissolved salts vary between 895 ppm, and 110567 ppm, (Table 5).

The TDS increases gradually from South to North (Figs. 10). This helps in forming salt crusts along the northern discharge area. The groundwater is recharged from the fresh surface water canals and irrigation practices through a high permeable vadose zone. The obtained results of environmental isotope analyses confirmed the impact of recharge to the shallow groundwater by El-Salam Canal and irrigation practices along its supply course. Figure (11) clearly indicates this relationship, where environmental isotope ratios reveals enrichment gradient towards the canal and irrigated areas, while, along the other side these ratios decrease showing depletion signature far from these practices. The higher depleted values represent the deeper groundwater along the southern desert fringes indicating an old water origin.

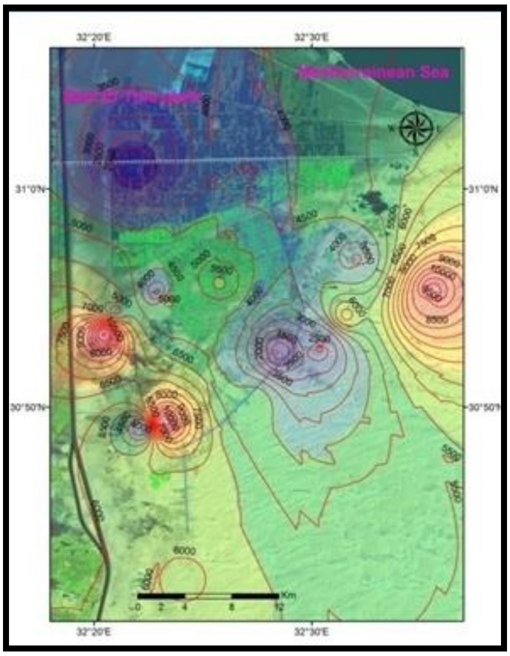

Fig. (10): Salinity distribution map in the groundwater of the study area (TDS values in mg/l)

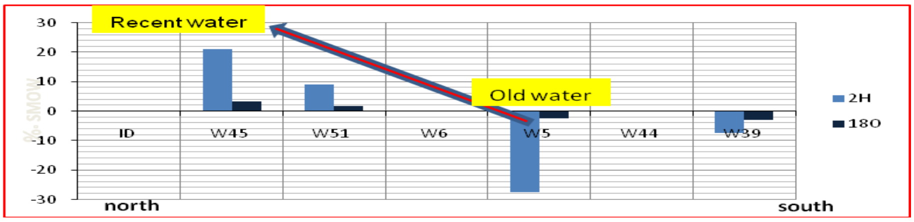

Figure (11): Distribution of environmental isotope (^{2}H and ^{18}O in SMOW0/$_{00}$) of the studied groundwater from south to north.

Table (5): Results of chemical analyses of the groundwater wells and auger hole water from the study area.

Well ID	TD m	X Lat.N	Y Long. E	NO_3 (mg/l)	TDS (mg/l)	Ion concentration in mg/l Ca	Mg	Na	HCO_3	SO_4	Cl	^{2}H SMOW 0/00	^{18}O
W45	105	30.8222	32.3866	32	10408	440	232	3085	142	2165	4342	21.0	3.46
W51	35	30.7652	32.3986	11	5722	70	108	1955	171	534	2870	9.1	1.76
W6	20	30.7030	32.4027	14	6074	324	234	1670	116	446	3273		
W5	100	30.6507	32.4012	6	2862	50	38	922	244	475	1124	-29	-2.2
W44	90	30.5569	32.5058	16	5012	112	48	1512	120	1190	2020		
W39	65	30.5022	32.5160	12	5400	122	52	1643	122	1221	1232	-8.0	-2.9
H1	6.0	30.9116	32.5861	2.4	9067	460	285	2491	91.5	1300	4437		
H2	5.0	30.8783	32.5061	3.2	1612	102	42	411	274	70	710		
H3	1.2	31.1461	32.5922	1.2	12208	700	404	3220	103	2100	5680		
H4	4.3	30.8372	32.4566	2	4826	200	175	1316	103	900	2130		
H5	0.85	31.1778	32.7267	1.2	17696	760	515	5170	73	2125	9052		
H6	1.2	31.1778	32.7267	2.4	16756	695	470	4865	79	275	9656		
H7	-	31.1197	32.6376	1.2	1080	102	66	165	195	125	426		
H8	23.5	30.8761	32.4763	2	1144	49	54	258	201	225	355		
H9	0.65	31.0719	32.5319	2.8	3520	248	83	870	274	800	1242		
H10	-	31.0719	32.5319	1.6	895	70	112	58	244	90	319		
H11	30	30.9038	32.5264	1.2	6173	148	162	1880	219	1100	2662		
H12	3.0	30.8888	32.3410	6	11056	55	164	4004	244	720	5908		
H13	5.5	30.9394	32.5366	1.2	4492	18	16	1713	122	265	2367		
H14	-	30.6587	32.2245	5.6	989	52	92	141	244	100	355		
H15	-	31.1686	32.5247	1.6	1162	49	75	247	207	85	497		
H16	5.0	31.0156	32.3640	1.6	1559	78	49	405	231	155	639		

Problem management

The control of water logging can be achieved using appropriate drainage system to prevent water discharge to the ground surface and causes soil salinization. The removal of the produced salts in the root zone would consequently take tens to hundreds of years, even under high washing (leaching) rates.

The most realistic way to prevent water logging and soil salinization is to manage the cause and cut off the supply of water that producing excessive groundwater recharge across agricultural landscape. Occasionally, groundwater is collected via open ditches to avoid water logging problem. However, such ditches take land out of production and require considerable cleaning and other maintenance. Instead, underground drains (Fig. 12) and dewatering wells are widely used to lower water level in the logged areas. In this study we simulate the problem and recommend some designs to solve and remediate its hazards.

From the above mentioned discussion, water logging history indicates that, the low lands and fish farms constitute the main core reasons of the problem. Also, the flat areas close to the irrigation canals are highly prone to water logging where a huge amount of water seeps from these canals. It was hypothesized that where the land surface exhibited negative curvature (i.e. micro depression) and low slope, surface and sub-surface water would accumulate, resulting in water logging and salinization due to the exposing of these logged water to evaporation. The existing of perched water conditions may help growing the problem especially, along El-Tina Plain area where a duplex soil type exists (Fig., 12). The restricting layer in the study area varies in depth between 1-3 m along this area.

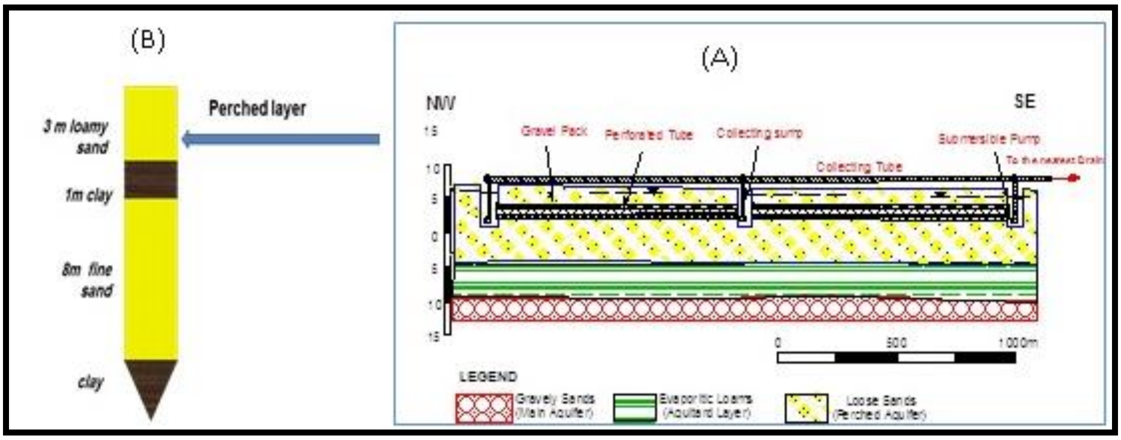

Fig. (12): Proposed tile drain design for improving drainage efficiency of the logged water sites (A) and, representative lithologic section of El-Tina Plain area (B).

For quick removal of excess irrigation water, construction of more surface drains following the natural gradient is required. The surface drains need to be properly maintained and reconditioned from time to time. Further all the surface drains should be linked to the field drains through link drains to dispose excess water; else there construction won't solve the purpose. Design of drainage system depends on many factors, which are; maximum height of water table; soil texture and characteristics; drainage rate and depths of the restricting layer. The simplest equations based on the assumption of horizontal flow, which is valid only if the impermeable restricting layer is at small distance below the drain as in our case of study. Determinations of drain spacing and effective depths in the study area were done using Hooghoudt equation (Hooghoudt, 1940 and Schilfgaarde, 1957) as follows:

$$\upsilon_a = 4Km\,(2D_e + m)/\,L^2$$

Where, υ_a is drainage rate (function of irrigation rate), **K** is hydraulic conductivity (varies between 0.4-3.9), D_e is effective depth of restricting layer below drain center (1-3m), **m** is height of water table above drain centers midway between drains (0.5-2m) and **L** is the spacing distance between drains (variable according to the soil and hydraulic properties).

These results were applied mathematically using groundwater modeling techniques, MODFLOW program (McDonald and Harbough, 1988). It is clear from these applications that improving drainage system using this type of tile drains is of prime importance to cease the recharge to the waterlogging sites and to avoid land degradation and soil salinization along infected sector. The drainage spacing distances varies between 18-60m according the site hydrology in the study area. Figure, 20 shows one case of the applied model. It is recommended to reuse the logged water for expanding irrigation to the neighboring desert fringes to the eastern and southern sectors. The drained water will be highly saline at the beginning of drain application and then, its salinity will reduces by time. This is of prime importance where up to 394.2 million m^3/year (1,080,000 m^3/day) of fresh Nile water is lost and returned back into the atmosphere due to the high evaporation rate in the study area.

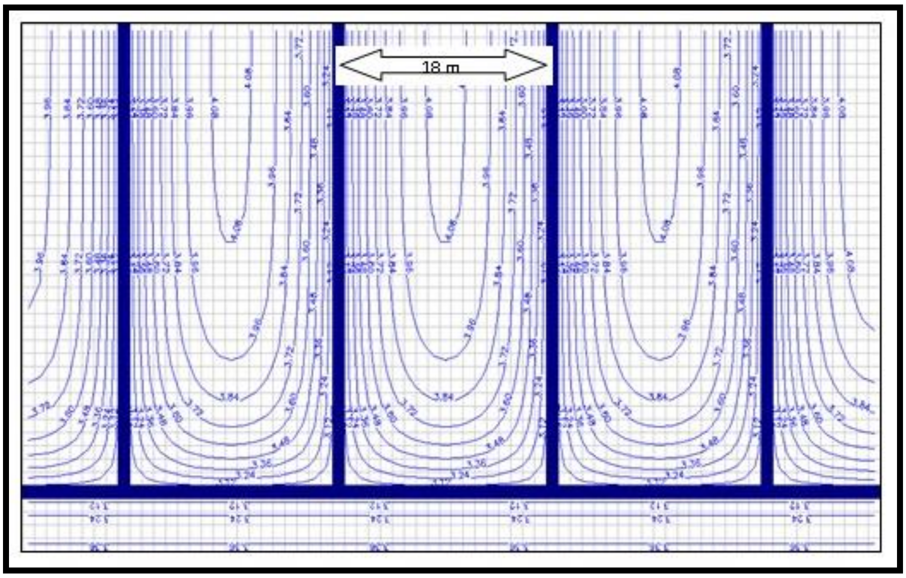

Figure (13): A case study of dewatering flow model of the proposed tile drain design along the logged water sites of El-Tina Plain area (drain spacing interval is 18m).

CONCLUSION

Data integration and analysis indicate that the area is under threats by four types of geoenvironmental hazards which are; Waterlogging; soil salinization; water pollution; and sea shore erosion. The main reasons of waterlogging are: (1) the development of a perched aquifer (duplex soil structure) over an extendable salty clay layer along the northern El-Tina Plain area; (2) the topographic relief changes and inundation of several micro-depression zones; (3) Seepage from El-Salam canal and its surrounding irrigation activities and (4) absence of adequate drainage networks. While, Soil salinization is highly related to the waterlogging,soil chemistry, depthto restricted layer and high evaporation rate that prevailed in the study area.Up to 18% of the El-Tina Plain area is drowning under the logged water.The wetland areas and waterlogging sites were increased from 25km^2 at 1984 to 180km^{2}km^2 in 2014 respectively after El-Salam Canal construction.

To remediate the problem, improving drainage density and reuse the logged water through pumping to the surrounding desert fringes are recommended. The present study proposes solution models for improving drainage efficiency using dewatering tile drain approach which will help bringing down the high water level and coping with shortage of water by saving up to 394.2 million m^3/yearof the lost irrigation water in the study area.

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تقييم الأثر الجيوبيئى لترعة السلام على التربة المحيطة ونظام سريان المياه الجوفية بشمال غرب سيناء – مصر

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الملخص العربي

تعتبر ترعة السلام واحدة من أكبر مشاريع الرى التى أقيمت فى بشمال سيناء عام ١٩٩٨. وتقدر مساحة الأراضى المستصلحة بهذا المشروع بمنطقة شرق قناة السويس بحوالى ٤٠٠٠٠٠ فدان. وتستمد ترعة السلام مياهها من فرع دمياط وتخلط بمياه مصرفى السرو وحادوس بشرق الدلتا بنسبة ١:١. وفى هذا البحث تم إستخدام صور اللاندسات الفضائية لدراسة تأثير ترعة السلام على منطقة سهل الطينة. وتم إختيار أنسب ثلاثة حزم مرتبطة لمراقبة التغيرات فى إستخدام الأرض خلال الفترة ١٩٨٤ – ٢٠٠٣ والفترة ٢٠٠٣-٢٠١٤. وتم أيضا تحديد نوعية المياه بناءا على المحتوى الكيميائى والبيولوجى والخصائص الفيزيائية والمحتوى النظائرى للعناصر الذائبة فيها والوصف الكامل لمكونات المياه التى يمكن أن تؤثر فى إستخدام المياه وفى تاريخ شحن المياه الجوفية. وبتكامل البيانات تبين أن المنطقة تعانى من أربعة أنواع من المخاطر الجيوبيئية تتمثل فى غدق المياه و تملح التربة وتلوث المياه الجوفية و نحر شاطئ البحر. وقد أظهرت النتائج زيادة مساحة الأراضى المعرضة للغدق من ٢٥ كم٢ عام ١٩٨٤ إلى ١٨٠ كم٢ فى عام ٢٠١٤ بمنطقة سهل الطينة. وقد زادت مساحة الأراضى المنزرعة زيادة كبيرة لتصل إلى حوالى ٨٩ كم٢ فى عام ٢٠١٤. وهناك عدة عوامل أثرت فى توزيعات الغطاء الأرضى بالمنطقة تشتمل على إرتفاع منسوب المياه الجوفية والتوزيع الغير مناسب للمصارف وإزدياد مساحات المزارع السمكية بالمنطقة. وتؤثر خصائص التربة تأثيرا كبيرا فى مدى قابليتها للتعرض إلى الغدق الأرضى وتملح التربة وذلك لتميزها بالنسيج المزدوج فى قطاع التربة الرأسى بسهل الطينة.