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BEACH FILTRATION FOR LOW COST RO DESALINATION AND ENVIRONMENT PROTECTION - A CASE STUDY OF SHARM EL-SHEIKH, SOUTH SINAI, EGYPT.

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ABSRACT

Egypt has considered desalination as a strategic option for coastal areas development. Sharm El-sheikh mainly depends on it for touristic development. The capacity of its desalination plants has increased from 25.000 m^3/day in the year 2001 to 150 000 m^3/day in year 2018. This has entailed daily discharge of large amounts of desalination reject (brine) into the surrounding environment. There are two different types of feeding water intake (beach wells and open seawater).The disposal of brine discharge can be either through the injection wells or by diffuse into open sea. This study aims to evaluate the potentiality of beach filtration technology for low cost reverse osmoses (RO) desalination and environment protection. The main aquifer in the study area is hydraulically connected with the sea water at Gulf of Aqaba. It has mean hydraulic conductivity of 35 m/day and thickness exceeds 50 meters. The reference water quality has total dissolved solids (TDS) range from 34000 to 35000 mg/l. The simulation model has shown that after 20 years of operation the drawdown will reach only 3-meters at the middle of the feeding wells field and the water salinity as TDS will increase to 45000 mg/l due to brine injection in the aquifer. Beach wells water has silt density index (SDI) value less than one while it reaches 4.4 for open seawater. High SDI values shorten the life of the membranes and increase the chemicals dose required for the removal of deposits on the membrane surface. The removal efficiency of both total organic carbon (UVA245) and dissolved organic carbon (DOC) in beach wells is 35% and 50% respectively. Also, the total coliform and algae are not detected at beach wells. Beach well filtration prevents clogging of desalination membranes and prolongs its life and reduces the chemicals used compared to direct seawater intakes. The natural filtration action of the subsoil reduces the cost of purchasing chemicals for membranes regeneration and the frequency of backwashing. The chemicals consumption rate per month that is used for beach well intake is much lower than that for open seawater intake desalination plant. Moreover, Beach filtration is environmentally friendly technique that helps to preserve the surrounding environment for sustainable tourism activities.

KEYWORDS: Beach well filtration; Desalination; Environment; Water supply; Egypt.

تحليه المياه الشاطئية منخفضة التكاليف باستخدام طريقة التناضح العكسى وحماية البيئة

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الملخص العربي:

اعتبرت مصر تحليه مياه البحر بمثابة خيار استراتيجي لإمداد المياه للمناطق الساحلية حيث تعتمد مدينة شرم الشيخ بشكل رئيسي علي مياه التحلية في مشروعات التنمية السياحية، فقد ازدادت قدرة محطات التحلية بها من ٢٥ ألف م ٣ / يوم في

عام ٢٠٠١ إلى ١٥٠ ألف م ٣ / يوم في عام ٢٠١٨، مما يستلزم تصريف كميات كبيرة من مياه المحلول الملحي المركز الناتج عن عملية التحلية يومياً في البيئة المحيطة. في هذا البحث تم اختبار نوعين مختلفين من مآخذ المياه للتغذية (الآبار الشاطئة مقابل السحب المباشر من مياه البحر) وطريقتين لتصريف المياه المالحة تتم باحدى طريقتين (الصرف في آبار الحقن مقابل الصرف المباشر على مياه البحر)، تهدف هذه الدراسة إلى تقييم إمكانات تكنولوجيا الترشيح الشاطئي لتحلية مياه البحر بتكلفة منخفضة وحماية البيئة. يرتبط الخزان الجوفي الرئيسي في منطقة الدراسة هيدروليكيًا بمياه البحر في خليج العقبة ، وله معامل توصيل هيدروليكي ٣٥ م/يوم وسمك يتجاوز ٥٠ متر. تتراوح ملوحة المياه (TDS) من ٣٤٠٠٠ إلى ٣٥٠٠٠ ملجم/لتر. لقد أظهر نموذج المحاكاة أنه بعد ٢٠ عامًا من التشغيل ، سيصل قيمة الإنخفاض في مناسيب المياه إلى ثلاثة أمتار فقط في وسط حقل آبار التغذية وملوحة المياه سترتفع إلى ٤٥٠٠٠ ملجم/لتر ، بسبب حقن المحلول الملحي في نفس الخزان الجوفي. تحتوي مياه التغذية من آبار الشاطئ علي قيمة SDI أقل من واحد بينما تصل إلى ٤.٤ في تلك القادمة مباشرة من البحر المفتوح. تقلل قيم SDI العالية من عمر الأغشية وتزيد من جرعة المواد الكيميائية اللازمة لإزالة الرواسب من سطح هذه الأغشية. تبلغ نسبة إزالة كل من الكربون العضوي الكلي (UVA245) والكربون العضوي المُذاب (DOC) في آبار الشاطئ ٣٥٪ و ٥٠٪ على التوالي. أيضا لم يتم رصد بكتريا البراز الممرضة والطحالب في آبار الشاطئ التي تغذي محطات التحلية ، كما يعمل الترشيح الطبيعي للشواطئ علي عدم إنسداد أغشية تحلية المياه وإطالة عمرها كما يقلل من المواد الكيميائية المستخدمة مقارنة مع مآخذ مياه البحر. يقلل الترشيح الطبيعي للتربة من استخدام المواد الكيميائية لتجديد الأغشية وتكرار الغسيل العكسي حيث أن تواتر تنظيف الأغشية يكون أقل بكثير، معدل استهلاك المواد الكيميائية المستخدمة شهريا في محطات التحلية المعتمدة علي الترشيح الطبيعي أقل بكثير من تلك المعتمدة علي التغذية المباشرة من البحر المفتوح. الترشيح الطبيعي للشواطئ هو تقنية خضراء تساعد في الحفاظ على البيئة المحيطة واستدامة الأنشطة السياحية.
الكلمات المفتاحية : تحليه الآبار الشاطئية – ألتحليه – البيئة – إمداد المياه – مصر.

INTRODUCTION

Desalination has been used worldwide to produce fresh water from saline and brackish water long time ago. Nevertheless, it consumes a lot of energy and causes harm to the environment. Recently, the reverse osmosis (RO) membranes have reduced the costs of desalination significantly but the environmental threat has continued (Missimer 2009; Ghaffour et al, 2013). The conventional process of RO desalination includes; chlorination, coagulation, flocculation and settling, filtration, oxidant removal, cartridge filter and finally to RO membrane. These pretreatment processes add high chemical load to the environment beside the desalination brine. Using beach wells as subsurface intake saves all these pretreatment processes and chemicals. Consequently raw water pass the cartridge filter to the RO membrane directly (Bartak et al 2012; Missimer et al 2013; Ghodeif and Grischek, 2015). Open seawater intakes have common problems including the installation of suction pipes and other facilities inside the sea that are frequently damaged due to the tides and ships navigations. Open seawater intakes also entrap marine biota and use a lot of chemicals to keep the intakes and associated piping clean of organic growth, seaweed, fish, jellyfish that accumulate on the suction screens (Lattemann and Hopner, 2008). All of these problems can be avoided through installation of vertical or horizontal beach wells as subsurface intake.

Egypt has considered desalination as a strategic water resources option for remote area development especially for the coastal areas. Different types of desalination intakes are experienced at Sharm El-Sheikh city along the Gulf of Aqaba (Figures. 1& 2). The old Sharm El-Sheikh desalination plant uses the open seawater intake while El-Shabab desalination plant uses the vertical wells intake.

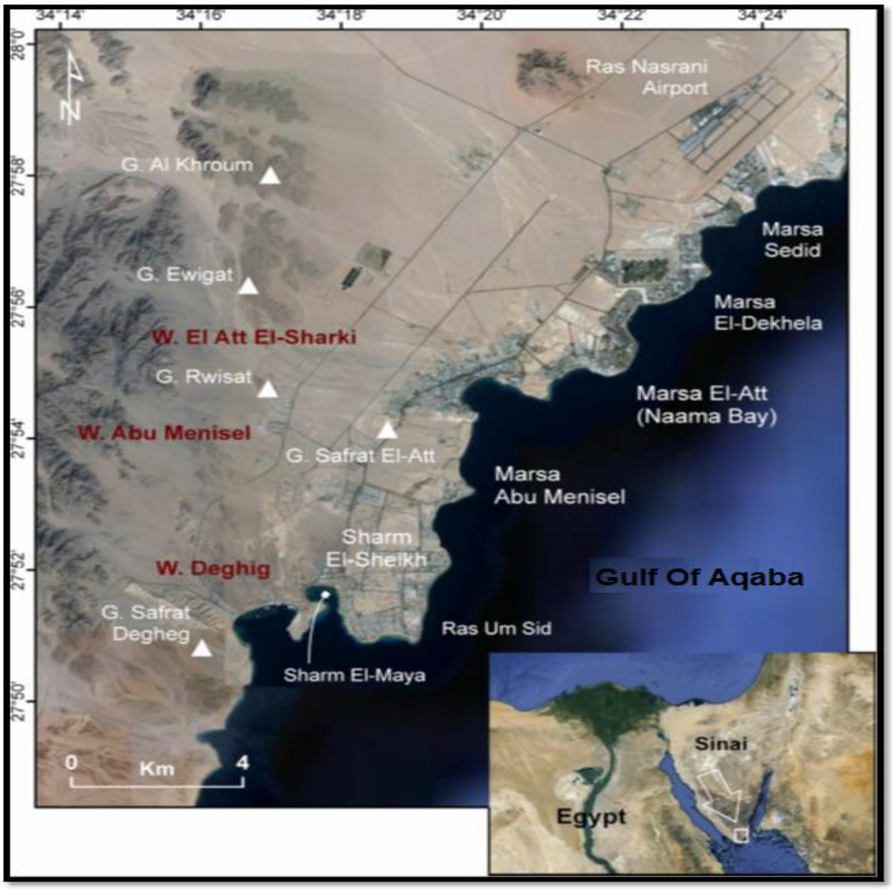

Figure 1: Location map of the study area (Sharm El-Sheikh, Sinai, Egypt)

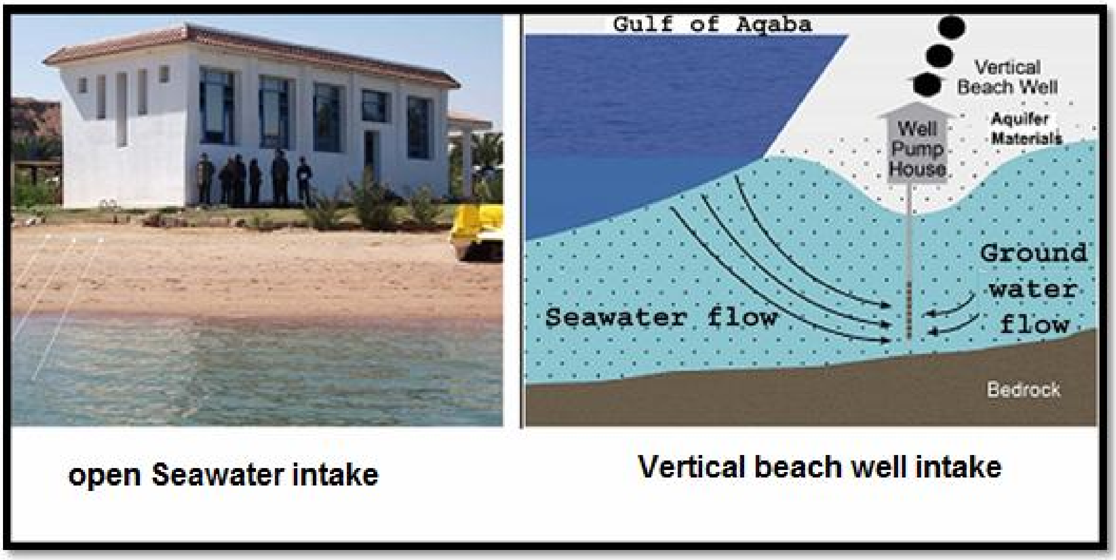

Figure 2: Open seawater intake (old Sharm El-Sheikh station) and beach well intake (El-Shabab) desalination plants

In the last two decades, Sharm El-Sheikh has witnessed a significant increase in the production of desalinated water to fill the gap due to the continuous water demand. The capacity of desalination plants in Sharm El-Sheikh has increased from 25000 m^3/day in year 2001 (Abou Rayan, 2001) to 150000 m^3/day in year 2018. This has entailed daily discharge of large amounts of desalination reject (brine) into the local aquifers. This has caused an increase in the salinity of the feed water from 44,000 mg/l in 2001 to 55,000 mg/l in 2018 at specific locations. Moreover, there is an environmental degradation of Sharm El-Sheikh environs due to the bloom in desalination and use of chemicals in more than one stage during desalination process. This has increased the total cost of water desalination and threaten the sustainable development. A comparison of desalination operations at two desalination plants of different water abstraction intakes at Sharm El-Sheikh is presented. One at Nabq Bay (El-Shabab plant), which relies on beach wells filtration to feed Reverse Osmosis (RO) desalination membranes while the other is the old Sharm El-Sheikh desalination plant which depends on direct feed from open seawater intake. The main aim of this study is to document the desalination operations at Sharm El-Sheikh, and to investigate the potentiality of beach filtration technology.

MATERIALS AND METHODS

The materials for this study include archival data, inventory results and water samples from desalination plants at Sharm El-Sheikh along the Gulf of Aqaba. The study, the authors have compared between two desalination plants that are using two different water abstraction intakes. The two desalination water intakes (1- El-Shabab plant at Nabq Bay; 2- old Sharm El-Sheikh plant) are distributed along the Gulf of Aqaba as shown by the numbers 1 and 2 in Figure 3.El-Shabab plant relies on beach wells filtration through beach sediments to feed Reverse Osmosis (RO) process the old Sharm El-Sheikh desalination plant depends on direct feed from open seawater intake. Water sampling and water quality analysis were done according to standard methods for the examination of water and wastewater (APHA/AWWA/WEF 2005). EC was measured in the field using WTW 350i multi-parameter sensor. Specific indicators such as the silt density index (SDI) and the UV absorbance at 254 nm (UVA254) have been measured. The SDI determination is based on the time elapsed to filter a volume of feed-water through a 0.45 micron filter at a feed pressure of 30 PSI. The UVA254 is measured using Spectrophotometer.

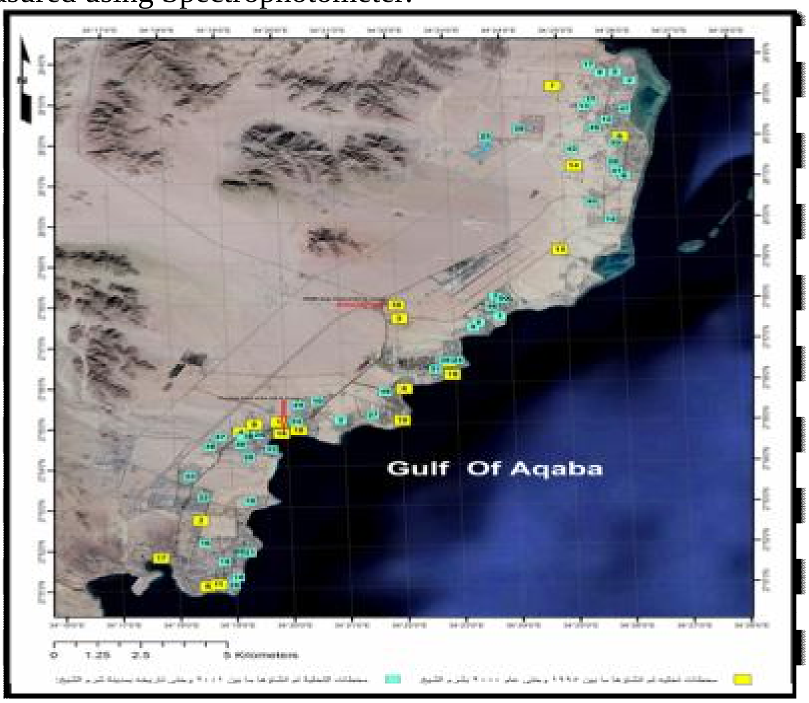

Figure 3: The distribution of desalination plants at Sharm El-Sheikh

A comprehensive inventory has been done for the existing desalination plants, the number of feeding and discharge wells in each station, as well as the quantities of desalinated water produced from each station, and the quantities of brine discharged into aquifers. A mathematical model was constructed, using Visual MODFLOW program, to investigate the impact of increasing desalination activities (the number of wells, amounts of feed water and the amounts of brine) on the water levels and the changes in water quality of feed water. Moreover, an economic analysis of desalination operations was conducted to estimate the chemical consumption, production costs and the price of desalinated water in two different desalination plants.

Hydrogeology of the study area.
Geologically Sharm El-Sheikh and its vicinity consist of Pre-Cambrian, Miocene and Quaternary Formations (Bentor and Eyal 1987). The Pre-Cambrian is represented by alkaline plutonic igneous rocks (mainly granite). It is distributed to the east of the study area (Fig. 4). It occupies Jebel Rowesat El-Nemar to the east of Nemaa Bay. The Miocene rocks are represented by Safra Formation at Jebel Safrat El Ate (lithology; dolomite., limestone., marl, shale., some sandstone) and Sharm Sandstone to the east of Um El-Seed Plateau. The distribution of Quaternary deposits is shown on figure 4 according to their corresponding number between brackets. The Quaternary deposits are consists of terrestrial alluvium (43); older reefs (44); younger reefs (45); calcareous sandstone (46) frequently oolitic and recent reefs (47) partly covered by thin alluvium. There is a major fault separates the Pre-Cambrian igneous rocks from the sedimentary succession in Sharm El-Sheikh. It extends NE-SW parallel to the Gulf of Aqaba direction.

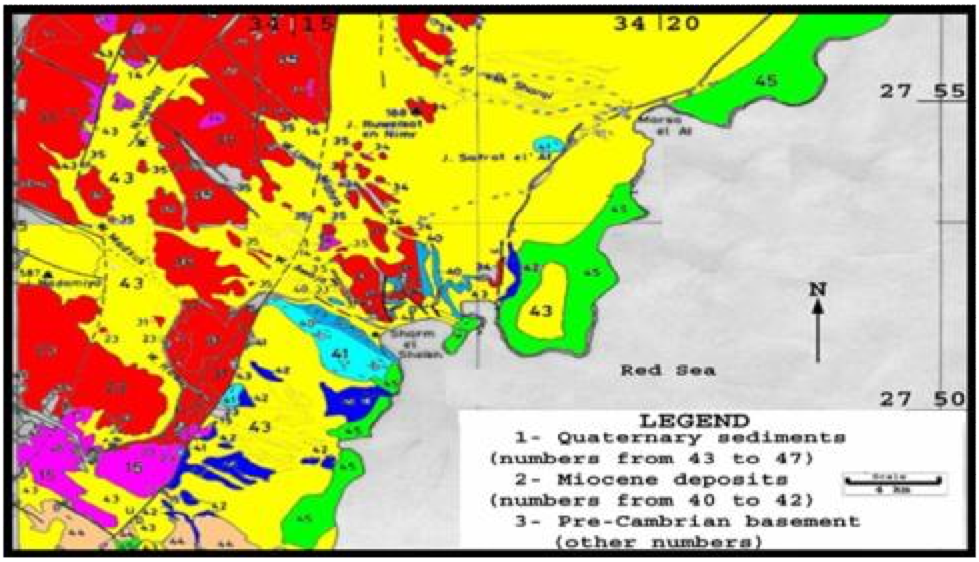

Figure 4: Geologic map of Sharm El-Sheikh (modified after Bentor and Eyal 1987)

Earlier water resources assessment studies in South Sinai have excluded Sharm El-Sheikh groundwater resources from its detailed investigations (Dames and Moore, 1985; Jica and WRRI, 1999). This may be due to poor hydrogeological recognition that has referred to local aquifer of low productivity and contains brackish groundwater. The Hydrogeological map of Egypt has delineated coastal plain aquifer in Sharm El-Sheikh. This aquifer has low to moderately productive layers of insignificant surface recharge (RIGW/IWACO,. 1988, updated 1999). Groundwater flow in Sharm El-Sheikh is generally from the western Pre-Cambrian fissured basement rocks to the Gulf of Aqaba (Issar and Gild, 1982). It is greatly influenced by the eastern rift system. Rifts are filled with permeable, down-faulted Mesozoic sandstones and overlain by younger Quaternary alluvial and coral reef sediments.

Recently, due to wide application of desalination plants in Sharm El-Sheikh and using aquifers for both raw water production and brine injection, the hydrogeological recognition has improved (Ramadan 2008; Shahatto 2003. Infra – Consult 2004). An example of lithology for the drilled wells is shown in figure 5. The feed wells of depths range from 120 to 180 meters while the depths of reject wells are range from 150 to 250 meters.

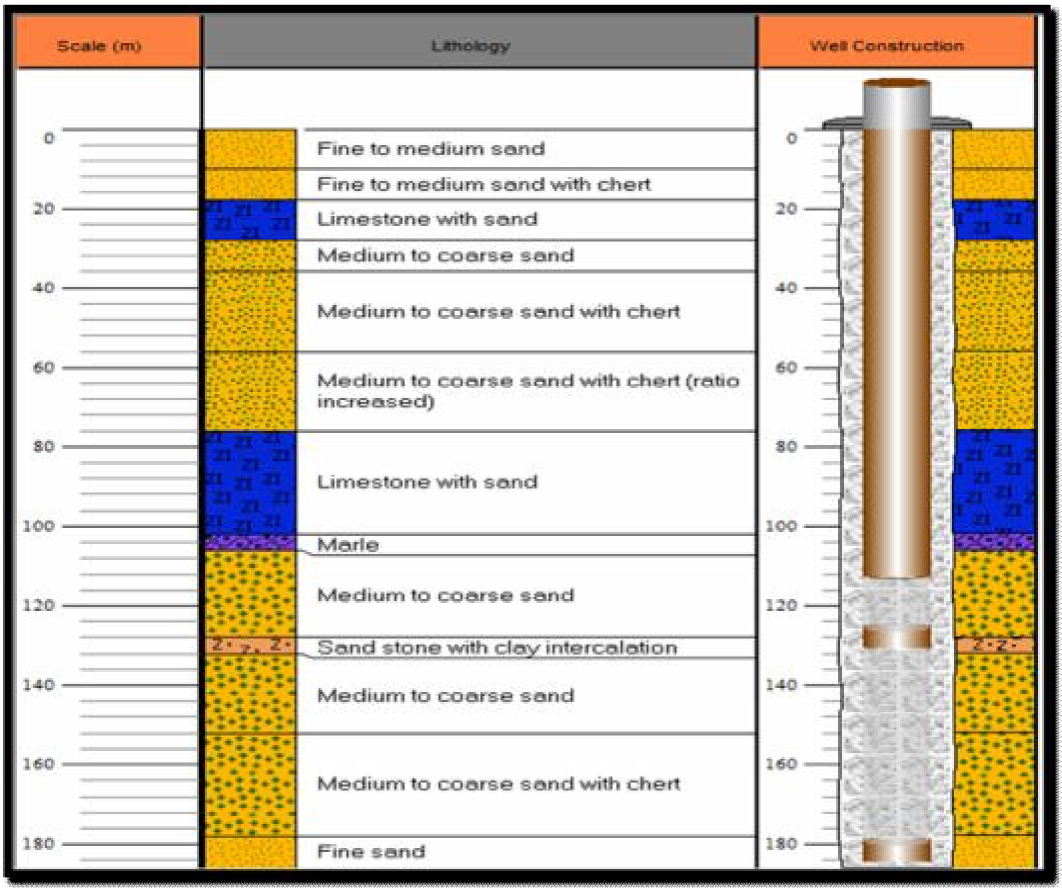

Figure 5: The lithology for one of the drilled wells in El-Shabab plant (WRRI, 2015).

Accordingly, the aquifers in the study are consists mainly of sand with intercalations of limestone and clay. The aquifer is unconfined and semi-confined and composed mainly from Miocene rocks (arkose sandstone and calcareous deposits). The sedimentary section of the sandstone range from 100 to 300 meters (Figure 6). The mean hydraulic conductivity of the aquifer is about 35 m/day.

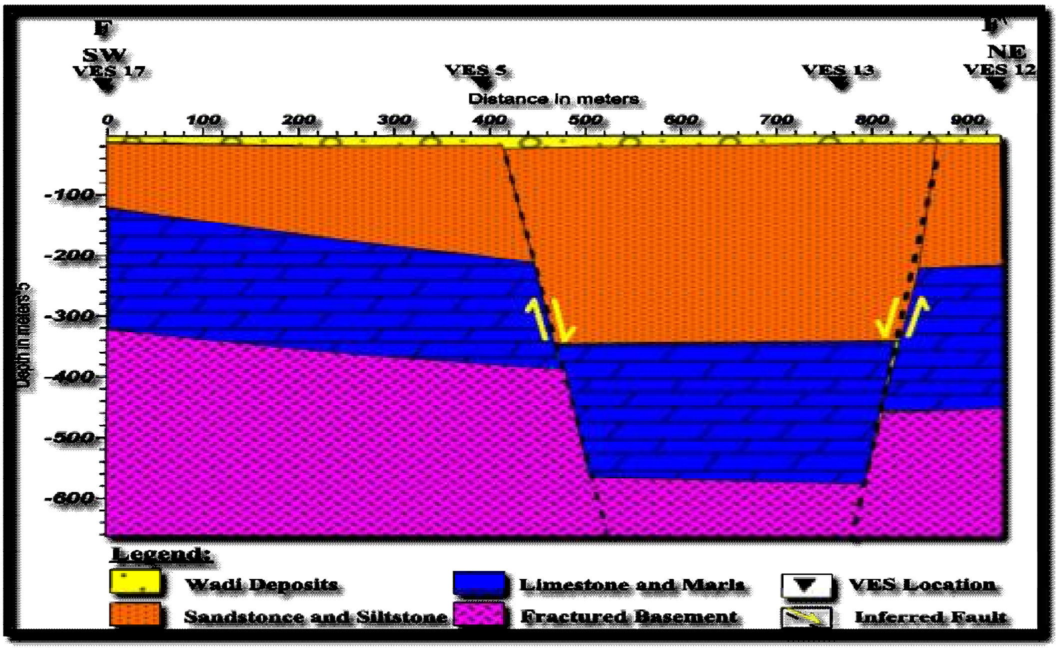

Figure 6: The main lithological layers at Nabq area (Geo-electric cross-section), (WRRI, 2015)

4. SIMULATION MODEL

4.1. Impact of Desalination

The impact of desalination on both water level and feed water quality at El-Shabab desalination plant has been simulated using visual MODFLOW program. The static water level ranges from 30 to 70 meters below the ground surface. The hydraulic gradient in the studied area and surrounding is very flat and about 0.00025. The maximum drawdown in the middle of the pumping wells (after pumping for 6 h at 90 m^3/h) was only 46-cm (Fig. 7). The reference water quality for year 2018 has TDS range from 34000 to 35000 mg/l (figure 8). After 20 years of operation the drawdown will reach 3 meters at the middle of the feed wells and water salinity as TDS will reach 45000 mg/l (Figs. 9 &10). This is mainly due to the continuous discharge of desalination brine at the same aquifer.

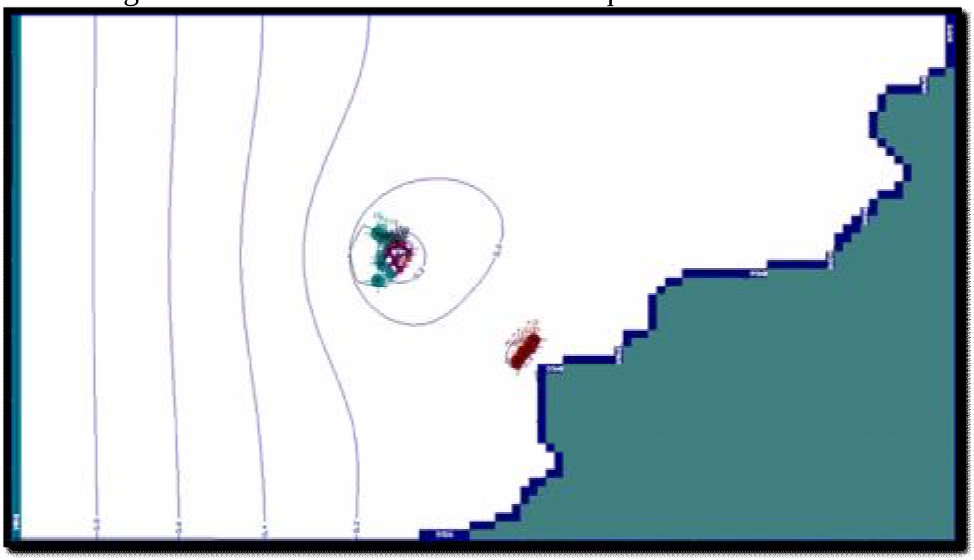

Figure 7: The distribution of the amount drawdown on the aquifer after 20 years of operation

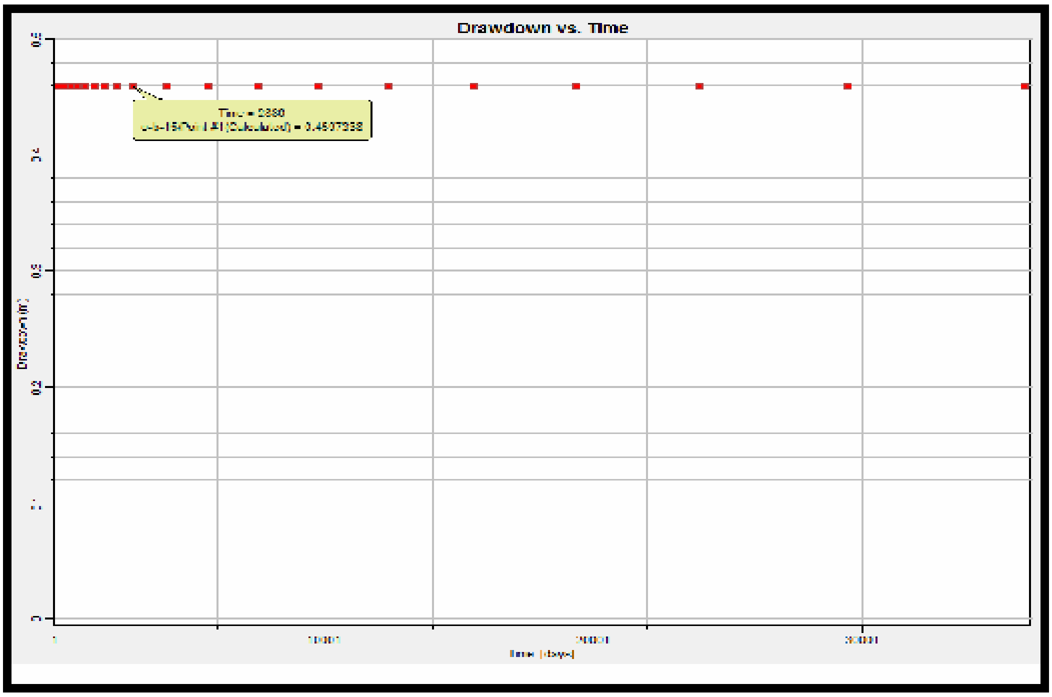

Figure 8: The change of drawdown with time at the middle of wells

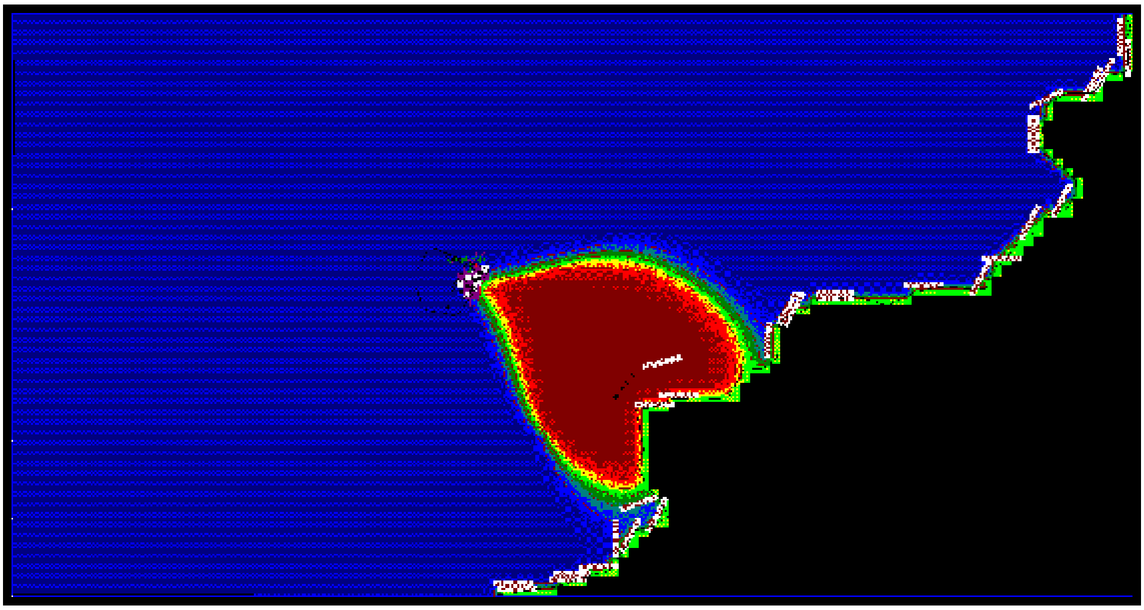

Figure 9: The distribution of the TDS in the aquifer after 20 years of operation

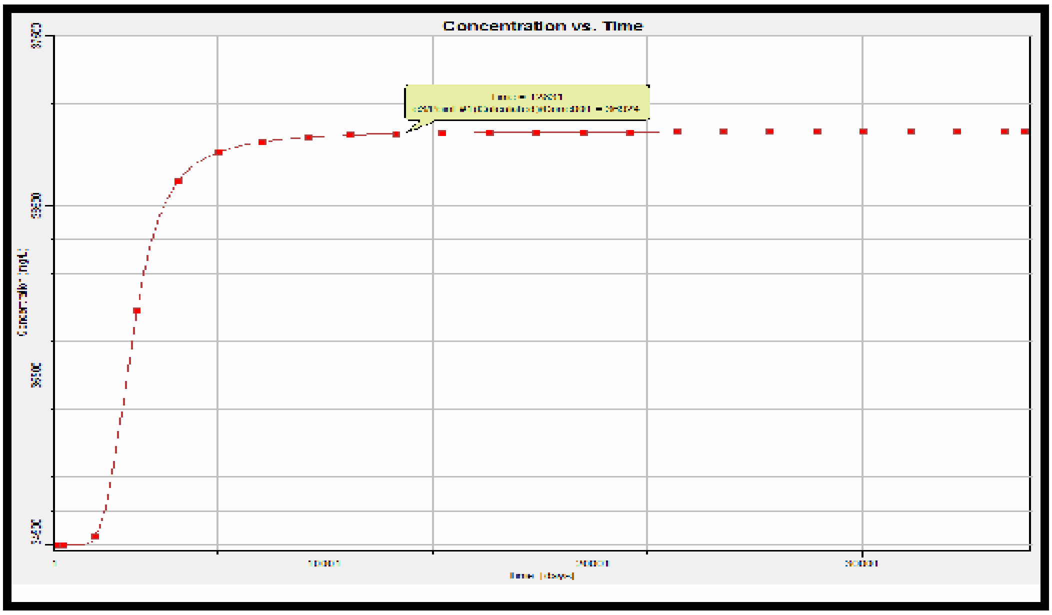

Figure 10: change TDS with time at the middle of wells

4.2. Comparison between well intake and open seawater intake.

The comparison of desalination operations has focused on both water quality of feed water and costs of operation in terms of specific parameters. El-Shabab plant use wells to supply feed water for RO process while the old Sharm El-Sheikh desalination plant depends on direct feed from open seawater intake. In terms of water quality of the feed water, that the great difference in terms of specific key parameters are shown in Table 1. The SDI value of feed water from beach wells is less than one while SDI value from open seawater is 4.4. The SDI value is a measure for the fouling capacity of water in RO systems. High SDI values decrease the life time of the membranes meanwhile increase the chemicals dose required for the removal of deposits on the membrane surface. The removal of total organic carbon expressed as UVA245 is 35% while the removal for the dissolved organic carbon (DOC) is about 50%. Both total coliform and algae are not detected at beach wells feed water while both are detected in appreciable counts at open sea water intakes. Thus the beach wells can be used as pre-treatment step to improve the raw water quality for RO desalination plants.

Table 1: Raw water quality

Wells intake (El-Shabab)	Open Sea water intake (old Sharm)	Unit	Parameters
7.48	8.17		pH
0.4	1.96	NTU	Turbidity
0.8	4.4		SDI
53200	61975	Micro S/cm	EC
34048	40500	mg/l	TDS
0.9	1.4	m-1	UVA254
NA	3.34	mg/l	TOC
0.9	1.6	mg/l	DOC
ND	205	cfu/100 ml	Total Cloiform
ND	141	cell/1 ml	Algae

The cost analysis for both desalination plants in terms of chemicals consumption and specifications is shown in Table 2. El-Shabab plant uses wells as pretreatment step while the old Sharm El-Sheikh plant uses open seawater intake from Gulf of Aqaba and further conventional train of pretreatment steps. The chemical consumption rate per month used for pre-and post treatment is about 25 % to 75 % lower than that at open intake desalination plant (Table 2). Accordingly, this will reduce the total cost for desalination operations and thus reduce the price of desalinated water.

Table 2: Comparison between El-Shabab (wells intake) and old Sharm El-Sheikh (open seawater intake) in terms of chemical consumption

Item	El-Shabab plant	Sharm El-sheikh old plant
Intake type	Subsurface water intake	Open sea water intake
Chemicals	Consumption / month*	Consumption / month*
Chlorine	1200-1500 Kg	4500 Kg
S.B.S	600-800 Kg	800-1000 Kg
Anti scalent	350-400 Kg	1000-1200 Kg
Coagulant	250-400 Kg	800-1000 Kg
Caustic soda	NA	250-350 Kg

*Chemical consumption calculated for average production of 10000 m^3/day

The cost analysis for the production of desalinated water at Sharm El-Sheikh (Table 3) has shown that the highest share of cost is due to energy consumption. The average total cost for one cubic meter is about 9 LE according to year 2018 prices. The usage of beach wells will reduce all the items directly (chemicals and labor) and indirectly (energy and initial costs). It will also the pretreatment steps, minimize membrane clogging and prolong its life time.

Table 3: Cost analysis for a public desalination plant of capacity 5000 m^3/day

Item	The cost per cubic meter (LE/m^3)
Investment cost (life time 10 years/365 days)	1.500
Electricity	3.750
Chemicals	0.820
Network substitutions	0.500
Spare Parts	0.500
Labor and others	0.850
Administrative expenses and profits	1.188
Total Actual Cost	9.108

CONCLUSIONS

In the last two decades, Sharm El-Sheikh has witnessed a significant increase in the production of desalinated water to face the continuous water demand. The capacity of its desalination plants has increased from 25000 m^3/day in year 2001 to 150000 m^3/day in year 2018. The main aquifer at Sharm El-Sheikh is hydraulically connected to the sea water and has high productivity in terms of hydraulic conductivity and thickness. The simulation model has shown that after 20 years of operation the drawdown will reach only 3-meters at the middle of the feed well field and the water salinity (TDS) will increase to 45000 mg/l due to brine injection in the same aquifer. Beach wells water quality in terms of SDI value, UVA245, DOC and the total cloliform and algae is suitable to supply RO membrane directly without comprehensive pre-treatment steps. This will prolong the life of the membranes and decrease the chemical dose required for the removal of deposits on the membrane surface. The average total cost for one cubic meter of desalinated water at Sharm El-Sheikh is about 9 LE according to year 2018 prices. The usage of beach wells filtration will reduce it significantly. It is recommended to use beach filtration by constructing beach well fields to feed multiple desalination plants. Other options and measures for brine disposal should be underta ken to improve the situation. It may include collection of brine from different desalination plants to one central place for industrial use and safe disposal.

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