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Salt-Tectonics Plays Major Role in Contributing High Seawater Salinity in Arabian/persian Gulf: A Constant Constrain on Seawater Desalination

[1]Nayyer Alam Zaigham, [1]Omar Siraj Aburizaiza,
[2]Zeeshan A. Nayyer, [1]Gohar A. Mahar and [1]Azhar Siddique

[1]Unit for Ain Zubaida Rehabilitation and Groundwater Research,
King Abdulaziz University, P.O.Box 80204, Jeddah, 21589, Saudi Arabia
[2]Department of Applied Physics, University of Karachi, Karachi, Pakistan

Abstract: Literature research indicates that Arabian/Persian Gulf is the second smallest and saltiest marine body in the world. In general, it is believed that anomalously high salinity of the Gulf is due to low precipitation, high rate of evaporation and limited freshwater pouring from rivers of Iraq and Iran. But present research study has identified that the geotectonic setup and the associated resulting active salt-tectonic processes are mainly causing constant enhancement of salinity in Arabian/Persian Gulf. The results indicate presence of numerous penetrations of salt domes, plugs and other diapiric structures almost all over the bottom and surrounding coastline areas, particularly coastal-belt of Iran, Strait of Hormuz and coastal areas of Qatar and UAE, which are the main inherent contributors for high salinity in seawater of the Gulf. Other factors, like, low precipitation, high evaporation, poor freshwater pouring of Iraq and Iran rivers and discharging back of highly concentrated brines, etc., are further augmenting Gulf's high-salinity. From the assessed salinity environment, it is inferred that present level of salinity will be 'higher to highest' in future affecting considerably the desalination activities in time to come. As the level of seawater salinity plays an important role for the efficient and cost effective seawater desalination activities, the present priorities should be reevaluated for efficient and sustainable water from desalination of highly salted-water of Arabian/Persian Gulf.

Key words: Arabian/Persian-Gulf · high salinity · salt-tectonics · Seawater-Desalination

INTRODUCTION

The Arabian/Persian Gulf (APG) lies between the Arabian Peninsula and the Iranian continental-mass (or the southern margin of Eurasia). It is the second smallest marine body [1]. Based on the customized bathymetry map analysis, APG is a shallow enclosed uplifted marginal saline-water body only with a narrow opening at Strait of Hormuz between southern Iranian coast and northeastern peninsular tip of UAE (Figure 1). Average depth is about 35m with maximum in the form of small pools of 100m depth along Iranian coastline only. Laterally, the Gulf extends over a distance of about 1000 km from Strait of Hormuz to Shatt-al-Arab northwestward. Width varies between 185 and 370 km with an average of 270 km covering area of 270,000 km^2. Volumetrically, the capacity for holding seawater was estimated about 9,400 km^3 that presently seems to be reduced under the huge reclamation activities for the coastal-offshore industrialization and urbanization by the peripheral Gulf's countries.

APG has the saltiest seawater in the world. The seawater salinity is even more than Red Sea, which is also considered the saltiest Sea. In general, the surface salinity in the gulf average plus 40‰, while shallow parts of the UAE coast have shown salinities ranging around 50‰, even rising to 70‰ in remote lagoons and coastal embayments such as the Gulf of Salwa [2-6].

Corresponding Author: Nayyer Alam Zaigham, Unit for Ain Zubaida Rehabilitation & Groundwater Research, King Abdulaziz University, P.O.Box 80204, Jeddah-21589, Saudi Arabia. E-mail: nazaigham@gmail.com.

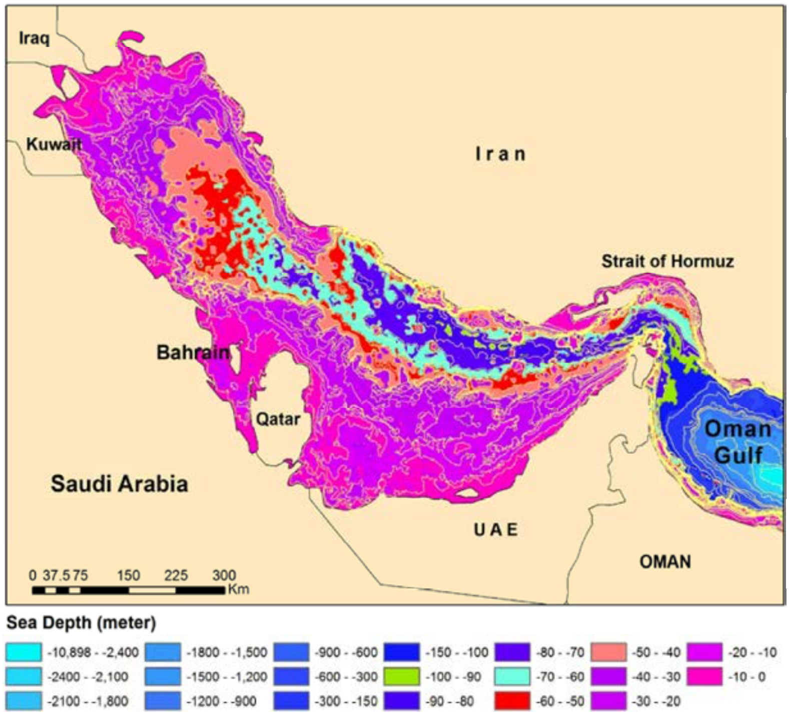

Fig. 1: Customized bathymetry map of Arabian (Persian) Gulf in relation to Oman Gulf and the Gulf's enveloping countries. Data source: NGDC-NOAA.

In general, the previous researchers considered the i) high rate of the evaporation and low precipitation under harsh arid climate, ii) limited freshwater pouring of coastal rivers, iii) partially isolation of Gulf from the open ocean and/or iv) other miscellaneous land-based urbanizational and industrial activities in the Gulf's coastal cities for contributing abnormally high salinity of seawater [2, 3, 7-14].

No doubt, these inferences may also be right, but as they are not consistantly renewable and thus may have relatively variable impact on the increase of the Gulf's salinity. During the present study, for the first time, the natural geological salt diapiric processes have been considered for the constant salinity enhancement of the gulf's seawater. It seems to be the permanent renewable source to abnormaly high salinity to Gulf, which was not considered during the previous studies.

Present paper focuses on the geotectonic setup and the associated salt-tectonics, which has mobilized the deep-seated thick Proterozoic-Lower Cambrian Hormuz Salt Series at surface in the form of salt domes, plugs and/or other dipiaric structures causing adverse impacts on the seawater quality and long-term sustainability of seawater desalination options in the APG coastal regions.

Arabian (Persian) Gulf and its Tectonic Setup: The western and southern rifts have separated Arabian Peninsula from the Afro-Arabian mega-landmass collectively in conjuncture with eastern and northwestern mega-transform/transcurrent faulting systems drifting towards northeast [15-19], which has caused enormous compression forces all along the Zagros Thrust-Fold-Belt (ZTFB) as also evident from the NW-trending movement of Arabian plate at average velocity of 5 cm/year [20]. APG lies on the northeastern margin of Arabian Peninsula in front of ZTFB in the zone of converging forces. Thus, it is inferred that these compressional forces are causing constant reshaping of APG.

Geologically, the present-day APG basin and its sub-basins are the remains of a once much larger depositional basin aligned NW-SE that existed throughout the geological history [21]. Ross and others [22] identified that during Mesozoic period most of Arabian Peninsula, Persian Gulf, south-western Iran and eastern Iraq constituted the Arabian platform. The emplacement of the Zagros mountains during the Neogene and Pleistocene have reduced the platform area to APG as a result of ongoing convergence between Arabian platform and Eurasian plate along the Zagros crush-zone. Other factors that contributed to the reduction of the Arabian platform include the uplift of

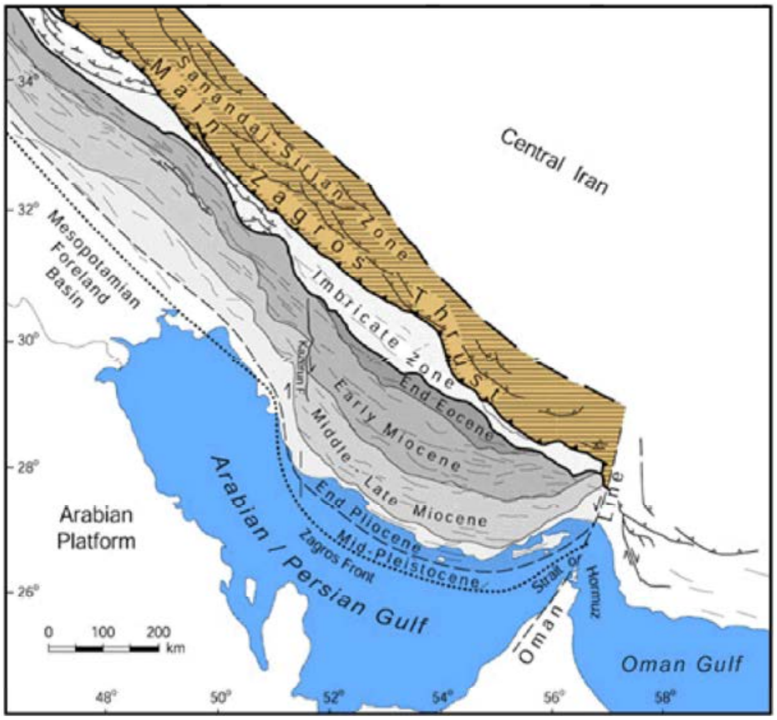

Fig. 2: Map shows increments of progressive growth in folded zone as it is arcuately widening from Eocene to the present towards southwest narrowing the Arabian/Persian Gulf [24].

Arabian Peninsula during the opening of Red Sea in Tertiary, the ongoing tectonism of the Infracambrian Hormuz-salt and up-warp of the platform sediment-cover by the basement uplift and/or salt tectonics.

Hessami *et al*. [23] and Hessami [24] identified southwestward advance of Zagros Fold-Front from central Iran (Figure-2). The observed syn-sedimentary structures indicated start of the Front's propagation since end-Eocene to its present position along APG and expected to continue further in future. Thus, further shallowing and narrowing of APG is inferred deforming the APG configuration and ultimately causing creeping deformation of the coastal industrial and urban development areas in time to come.

APG does not represent an oceanic bottom crust. In fact, APG was formed as a result of collision and consequent northward slight tilt of Arabian Plate against the ZTFB front to form the APG foreland basin instead of rifting like Red Sea. The basin is asymmetrical in NE-SW cross-section with the thickening of the Phanerozoic sedimentary sequence from 4,500m near Arabian Shield to 18,000m beside the main ZTFB. At the base of sedimentary sequences, a 1-2 km thick Late Proterozoic-Lower Cambrian Hormuz Salt-Series occurs at an average depth of 9000m in and around APG overlying the Precambrian metamorphic basement [25]. Under the prevailing tectonics, the reactivation of preexisted strike-slip mega-faults of basement and the overburdened salt-buoyancy allowed the deep-seated Hormuz-Salt to squeeze out as salt-piercements since Neogene period and also the north-trending basement uplift produced the rows of giant anticlines within onshore platform areas of Saudi Arabia [23, 25, 26]. Some of them also extend across APG, like Qatar anticlinal structure. Present bathymetric analyses also reveal presence of salt-protruding-features almost throughout the bottom of APG. Even numerous salt-features appear at the surface of APG as salt-islands.

Factors Contributing High Salinity to Gulf's Water: Generally, it was observed that the evaporation greatly exceeds as compared to the precipitation as a result of prevailing high temperatures in arid conditions and the limited river runoff into the Gulf. Consequently, these conditions were considered the main causative factors of high salinity in APG [7,8,14]. No doubt, this conclusion may be one of the augmenting factors for high salinity, but during present study, another natural causative factor is taken into consideration for the first time, which seems to be the constantly renewable main source contributing outstanding higher salinity to APG.

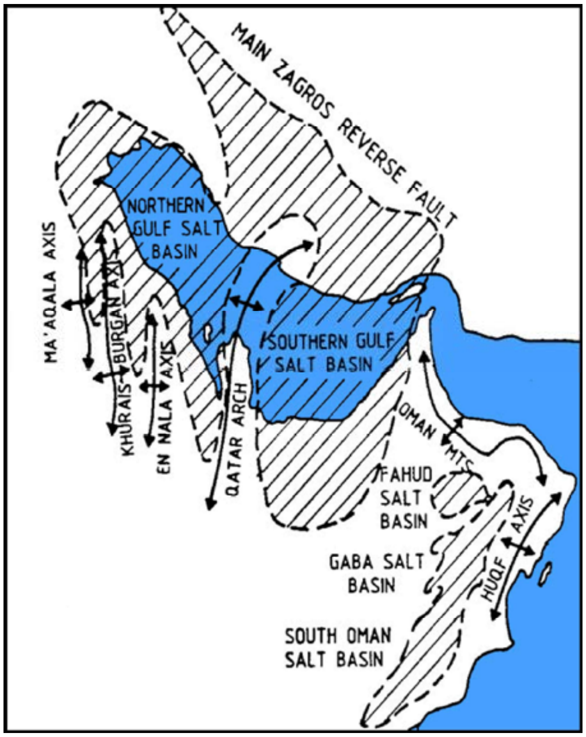

Fig. 3: Map shows the subsurface basin continuation of the thick Late Proterozoic-Lower Cambrian Hormuz Salt Series in and around the Arabian/Persian Gulf as shown by inclined parallel lines, the major anticlinal/horst structures with north trending axes, and Arabian/Persian Gulf, Gulf of Oman and western coastal area of Arabian Sea as shown by blue colour [26].

In fact, the presence of thick Hormuz Salt-Series sandwiched between Phanerorozoic thick sedimentry sequance and highly metamorphosed pre-Cambrian basement and the associated active salt-tectonic processes, play an important role for constant contibution of high salinity to APG creating renewable adverse impact to seawater quality.

Hormuz salt-series (evaporites) occupy three main depositional basins, i.e., western Gulf Salt-basin covering offshore and much of onshore Saudi Arabia, eastern Gulf basin in the offshore of UAE and southeast Iran and southeastern Oman salt-basin (Figure-3).

The Hormuz evaporites have risen to surface piercing through overlying thick sedimentary rocks in the form of salt dome, plugs and other diapiric structures. It was inferred that the overburden, the salt buoyancy and basement faulting integratingly produced the salt-flowage anticlines and as such rows of anticlines were formed by compressional-folding in Late Pliocene [25]. The late Precambrian, highly plastic Hormuz salt layer acted as a decoupling layer, disconnecting the sedimentary cover structures from the crystalline basement structures, which allowed the crystalline basement to deform by faulting while the sedimentary cover deforms mainly by ductile folding [27]. The NE-SW cross-section (Figure 4) highlights the Hormuz Salt layers in black and the general structure of the Zagros Fold Belt sedimentary cover, in contrast with the faulted nature of the upper basement.

It was also inferred that the left-lateral strike-slip faults in the basement and the Zagros thrust/reverse fault zone compressed the deep-seated Hormuz Salt to appear as prominent salt piercements at the surface in the form of salt-dome under the complex tectonics prevailing in the surrounding areas of the Arabian (Persian) Gulf.

More than 200 salt-plugs have been reported [28] only in the Zagroz-south region of Iran and also in northeastern offshore area of APG across Strait of Harmuz (Figure-5). More recently, Amini *et al*. [29]

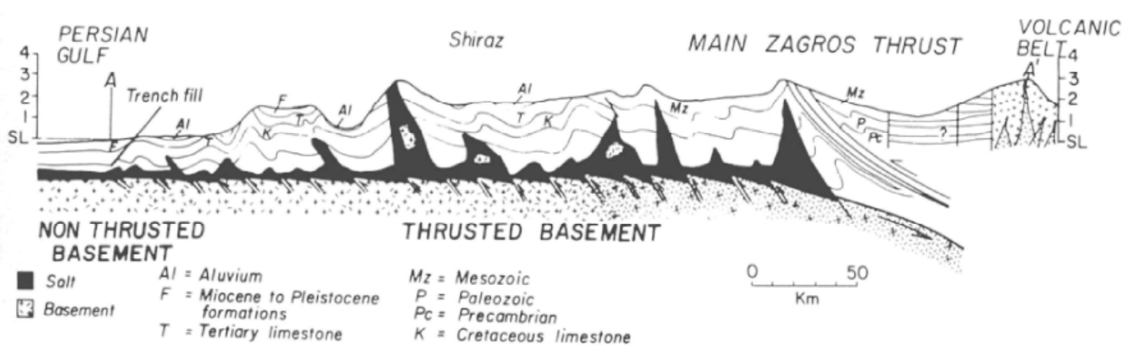

Fig. 4: Cross-section shows the general structure of the Zagros in north of Arabian/Persian Gulf, highlighting the Hormuz Salt layers in black. The cross section demonstrates the folded nature of the sedimentary cover in contrast with the faulted nature of the upper basement [35].

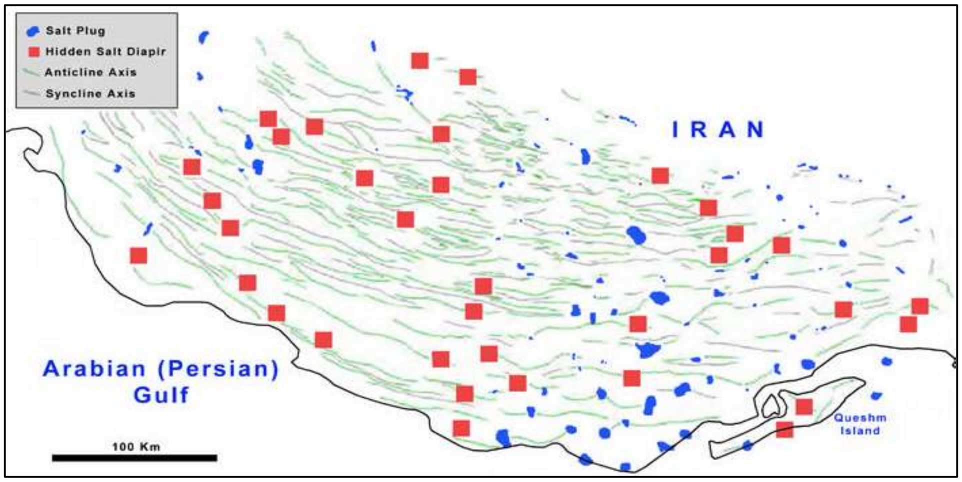

Fig. 5: Map shows the exposed salt-structures (Blue), the hidden salt diapirs (Red) and the folding trends in the southern Iran along the northern coastal area of Arabian/Persian Gulf [28].

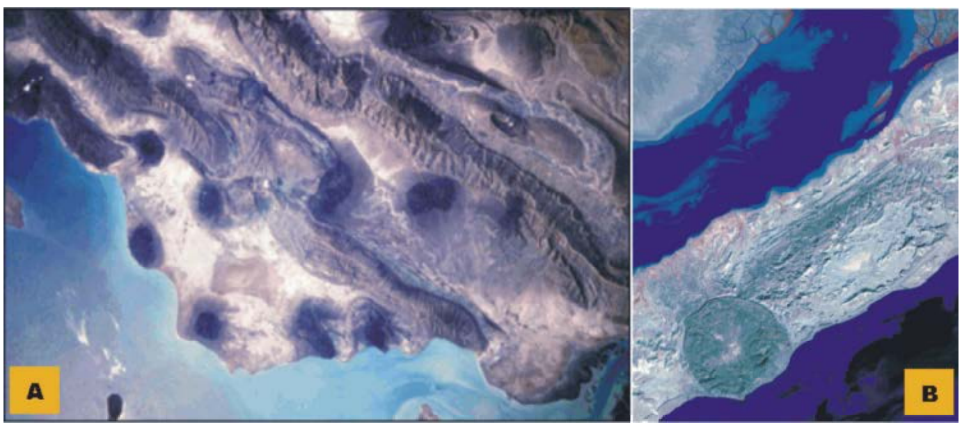

Fig. 6: A: Satellite image shows an excellent view of fold structures and the salt domes diaperically exposed in the north of Strait of Hormuz at the southern coastline of Iran. Image source: Sullivan (1984), and B: Qeshm Island floating in Straits of Hormuz at southeastern edge of Iran. Salt dome stands out in the image at lower left with the sedimentary rocks. Image source: ERSDAC 2010Figure 7: Customized bathymetry shows the distribution pattern of salient salt domes, plugs and other daipiric salt structures within Gulf's basin.

reported more than 500 exposed and/or buried salt daipiric structures in Iran along the northern coastal areas of APG.

Space-shuttle view of the earth shows specticular anticlinal fold structures and diapiric salt-domes exposed on the shore of APG in north of Strait of Hormuz [30]. The salt-domes have penetrated and risen through younger sediments to reach at the surface from deep-seated thick Hormuz salt-horizon (Figure 6A).

A more detailed view of exposed salt-plug is seen on the ASTER image of Qeshm Island that is also situated in Straits of Hormuz at southeastern offshore edge of Iran (Figure 6B). Similarly, the salt-cored offshore islands of Qatar [31], the salty-gypsum diapiric Hormuz Island [29] and the salt diapiric structures in Straits of Hormuz [32] have also been identified in APG.

Moreover, numerous salt-diapiric stock-like structures have also been identified, during present analyses of the customized bathymetry map. A randomly scattered pattern of these small diapiric salt-structures has been observed almost throughout the bottom of APG (Figure 7). Based on the actively ongoing intense tectonic convergent activities between northwestern rifted Arabian-continental plate margin and the overriding ZTFB-front, it is inferred that such salt features may keep piercing in future at the bottom and surrounding areas of APG from the deep-seated Hormuz evaporites.

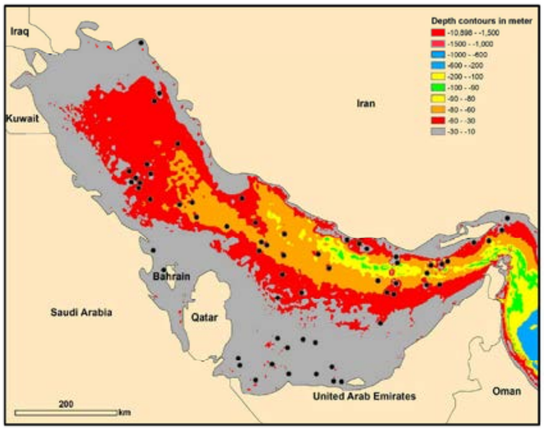

Fig. 7: Customized bathymetry shows the distribution pattern of salient salt domes, plugs and other daipiric salt structures within Gulf's basin.

In addition to the deep-seated thick Hormuz-Salt formation, the overlying younger sedimentary sequence also contains numerous salt and anhydrite horizons, interbedded with mainly limestones [33], on which the APG asymmetrical basin was developed. Based on all of these subsurface geological findings, it is inferred that the activation of the salt-tectonics mainly control the extreme salinity environments in addition to other factors. The seawater quality is further being deteriorated to the level of irreversible crisis by the huge anthropogenic activities related to the faster urban and multidisciplinary industrial developments in and around Arabian/Persian Gulf.

DISCUSSION

In general, the dominant water circulation pattern in APG is counter clockwise with respect to Oman Gulf. Surface normal oceanic salinity water currents flow into the APG through the northern part of the Strait of Hormuz as a wedge of less saline water, which penetrates deep into the APG along the Iranian coast [4, 7], increasing in salinity and exiting along the bottom through southern part of Strait as dense hyper saline water [34]. The whole cycle of this process generally takes about 1-3 years depending upon several factors.

It is inferred that the combination of two coincidences, i.e., the presence of exposed salt structures on the surface and the westward anti-clockwise seawater surface current-flow into APG from Oman Gulf passing through northern part of the narrow passage at Strait of Hormuz, plays the main role in creating high salinity environments in APG. When the normal oceanic salinity water of relatively low density enters into the northern part of Strait of Hormuz, a significant amount of salt was and/or is being eroded by such currents from the exposed salt domes and other diapiric salt structures within the Strait as well as all along the southern Iranian coastline. Concequently, the natural rock salt gets disolved and ultimately mixed with inducted seawater causing enhancement of its salinity and consequent higher density. Subsequently, the renewed hyper-saline water starts panetrating into deep of APG and the eroded over saturated recedues of salt also deposited in the Gulf basin from these salt-structures.

It is also inferred that the sedimentary rocks interbeded with salt and evaporite layers, on which Gulf's basin was developed and the salt-diapiric structures intruded from the deep-seated Hurmuz Salt formation in the bottom region may have their own salinity contribution to Gulf's water. Keeping in veiw of the discussed prevailing natural high salinity environment, it is anticipated that the constant extraction of potable water and the consequant reinduction of highly concentrated enormous brines and other polluted effuenlent dischages from the desalination and other industrial sectors, may convert the APG into Dead Sea and would affect the water-supplies from the desalination facilities in future.

CONCLUSIONS

- The active salt-tectonics prevailing in and around the APG play the key role in contributing hyper-salinity to the water of APG.
- The salt-structures exposed to the surface due to the tectonic mobilization of the deep-seated Hormuz Salt Series and the interbedded evaporate layers in the younger sedimentary sequences on which the Gulf was developed are the primary source for contributing high salinity in APG in addition to other secondary sources like high evaporation verses low precipitation and/or limited freshwater from rivers of Shatt-al-Arab.
- The constant huge extraction of potable water and conseqent reinduction of highly concentrated enormous hot brines produces by the desalination plants and the polluted effuenlent dischages from other industrial sectors, may convert the APG into Dead Sea in future.
- Thus, the over critical deterioration of the Gulf's water quality will be detrimental to desalination processes threatening the sustainable water-supplies from the environmentally dying Gulf in future.

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