European Water 57: 497-503, 2017.

Comparison of SGD rate between northern-southern coastlines of the Persian Gulf using RS

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Abstract: Submarine Groundwater Discharge (SGD) is defined as any subsurface flow of water from the land into the sea. In this research, we have tried to use remote sensing technique to determine the potential areas for SGD in southern coastlines of the Persian Gulf - around Bahrain where submarine freshwater springs have long been known- and a section in northern Persian Gulf coastline opposite to Bahrain. For this purpose, first necessary corrections (atmospheric, radiometric, and geometric) were made on the obtained Landsat 8 data in 2016 across the study area. Then, by mapping sea surface temperature (SST) and standard temperature anomaly (STA), probable anomalous areas caused by SGD into the coastlines of the Persian Gulf were identified and mapped. Results show that although 29 submarine freshwater springs are known to exist around Bahrain, thermal anomalies in northern coastlines of the Persian Gulf are much more than that of the southern coastlines; we could not detect significant thermal anomaly around and near Bahrain. Therefore, it is likely that the rate of SGD into north of the Persian Gulf is considerably high and much more than in the southern Persian Gulf. The approach implemented in this study can be used for any coastal regions that may have an interaction with coastal aquifers especially for other parts of the Persian Gulf coastlines.

Key words: SGD, Submarine Spring, Remote Sensing, Persian Gulf

1. INTRODUCTION

Submarine Groundwater Discharge (SGD) is defined as any subsurface flow of water from the land into the sea. A significant component of water cycle, SGD is highly important for management of coastal areas for at least three reasons including chemical and ecological effects of SGD, loss of fresh water resources through SGD, and geotechnical aspects of coasts, e.g. slope instability (Burnett et al., 2006). A predecessor of SGD, Submarine Freshwater Discharge (SFD) has been known for many centuries; for example, phenomenon of the submarine karstic springs was recognized as early as in the first century BC (Ford and Williams, 2007). Because of the difficulty in assessing and understanding, both SGD and submarine freshwater springs were neglected for many years. In fact, the term SGD which was previously known as SGWD, has appeared in the literature in the early 1970's or even before. During the years, a variety of techniques have been implemented to measure SGD including seepage meters, seawater temperature survey using marine navigations, thermal remote sensing and TIR, seawater electrical conductivity surveys, geochemical tracers, hydrological and hydrogeological modeling, water budget calculations, geophysical methods, and radioisotopes that have been presenting several references about these.

Thermal remote sensing is one of the most effective methods for identifying SGD sites. It has been demonstrated that thermal remote sensing is a powerful tool for pre-screening the whole area (Schubert et al., 2014) and detecting the SGD potential sites in order to narrow down the field survey locations (Hennig et al., 2015). This technique is based on thermal gradient between incoming groundwater and the ambient sea water. Landsat data is one of the best datasets in this regard.

In this paper we have tried to use thermal remote sensing technique for assessing areas with likely SGD potential in southern coastlines of the Persian Gulf - around Bahrain where submarine freshwater springs are very well known - as well as a section of the northern Persian Gulf that is located on the opposite side to Bahrain. This research is a part of a larger study to locate submarine freshwater springs in the northern Persian Gulf area.

2. MATERIAL AND METHOD

2.1 Study area

Persian Gulf is a semi-enclosed marginal sea, 200–300 km wide, with a mean depth of 35 m and a total volume of 6000 km^3 located in the south of Iran and is connected to the Oman Gulf through the narrow Strait of Hormuz. The study area is a rectangle located on two sections of the southern and northern coastlines of the Persian Gulf (Fig. 1). The southern section is situated around Bahrain with 29 submarine freshwater springs that are known for long time (Al Bassam and Tiro, 2011). The northern section is located on a part of Iranian shorelines opposite to Bahrain where there is no scientific report of submarine springs.

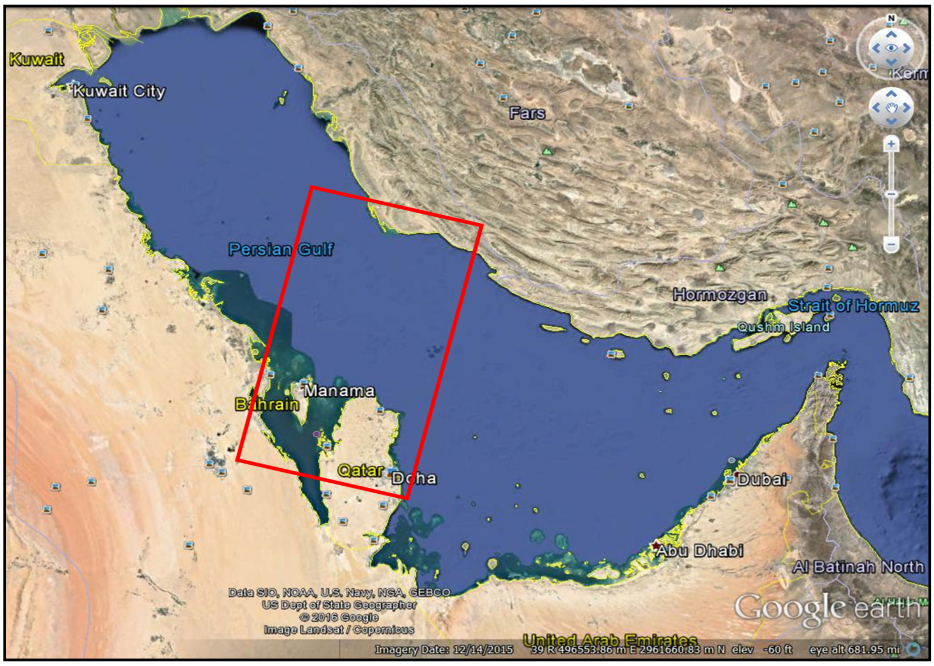

Figure 1. The location of the study area in southern Iran and Bahrain.

2.2 Method

The feasibility of using temperature as a groundwater tracer was recognised in the early 1900's (Anderson, 2005). It has also been demonstrated that remote sensing methods have applicability for recognising temperature difference between surface water bodies and discharging groundwater (Wilson and Rocha, 2016). In this study, we have used Landsat 8 thermal data. Landsat 8 satellite was successfully launched on February 11, 2013, carrying two sensors on-board: (1) the Operational Land Imager (OLI) and (2) the Thermal Infrared Sensor (TIRS) with two spectral bands in the long wave infrared region (LWIR). To achieve the goal, first, necessary corrections (atmospheric, radiometric, and geometric) were made on Landsat 8 data in 2016 (February, March, May, October) across the study area. Then, according to the metadata of the bands for Landsat 8 (thermal constant, rescaling factor value, etc.) as shown in Table 1, Sea Surface Temperature (SST) was mapped using the Formulas 1-4.

Table 1. Metadata of Landsat 8 bands (USGS, 2016)

	Band 10	Band 11
Native Resolution	100 m	100 m
K1	774.89	480.89
K2	1321.08	1201.14
M_L	3.3420E-04	3.3420E-04
A_L	0.10000	0.10000

The digital numbers of Band 10 were converted to the brightness temperature by using the metadata. These were first converted to radiance by following relation:

$$L_\lambda = M_L \cdot Q_{cal} + A_L \quad (1)$$

where, L_λ is top of atmosphere spectral radiance, M_L is band-specific multiplicative rescaling factor, Q_{cal} is digital number, and A_L is band-specific additive scaling factor.

For acquisition of brightness temperature, the following relation was used:

$$BT = K_2/\ln(K_1/L_\lambda + 1) \quad (2)$$

Then, SST was mapped by following formula:

$$SST = BT/\ln \varepsilon \cdot (BT/\rho) \cdot w+1 \quad (3)$$

$$\rho = hc/s \quad (4)$$

where, ε is emissivity which is 0.989 for sea water (Srivastava et al., 2009; Wilson and Rocha, 2016); w is radiance emitted wavelength; h is Planck's constant ($6.626 \cdot 10^{-34}$ JS); c is speed of light ($2.998 \cdot 10^{8}$ m/s) and s is Boltzmann's constant ($1.38 \cdot 10^{-23}$ J/K).

To recognize where on the SST map anomalous thermal arrangements potentially reveal groundwater inputs, and to allow comparisons across image frames, thermal anomaly (TA) and standardised thermal anomaly (STA) maps were created using formulas 5-6 (Wilson and Rocha, 2016):

$$TA = Tp - \check{T} \quad (5)$$

where, TA represents temperature anomaly (ºC), Tp is the temperature value specific to each pixel in the scene (ºC), and $\check{T}$ is the average temperature value for the sea surface (ºC).

$$STA = TA/\sigma \quad (6)$$

where, STA (dimensionless) represents standardised thermal anomaly, TA is temperature anomaly and σ is standard deviation.

Finally, using SST and STA maps, probable anomalies caused by submarine groundwater discharge into coastlines of the Persian Gulf were identified and mapped. All calculations were carried out by using ENVI 5.3 and Arc Map 10.3.1 software.

3. RESULT AND DISCUSSION

Figures 3-6 depict STA maps for the study area.

Available multi-national oceanographic observations for the Persian Gulf region are limited, because investigations have been undertaken by individual countries in their own coastal waters (Moradi and Kabiri, 2015). So far, use of remote sensing in Persian Gulf area have been limited to environmental purposes, habitat mapping, coastal and hydro-biological processes, and variability of SST and Chlorophyll-a (Al-Ghadban, 2004; Alsahli et al. 2012; Moradi and Kabiri, 2015) with no research about SGD. Satellite remote sensing allows information on SST to be mapped at moderate resolution, over large areas and long periods of time; by analysing these maps we have identified and recognized the potential SGD zones.

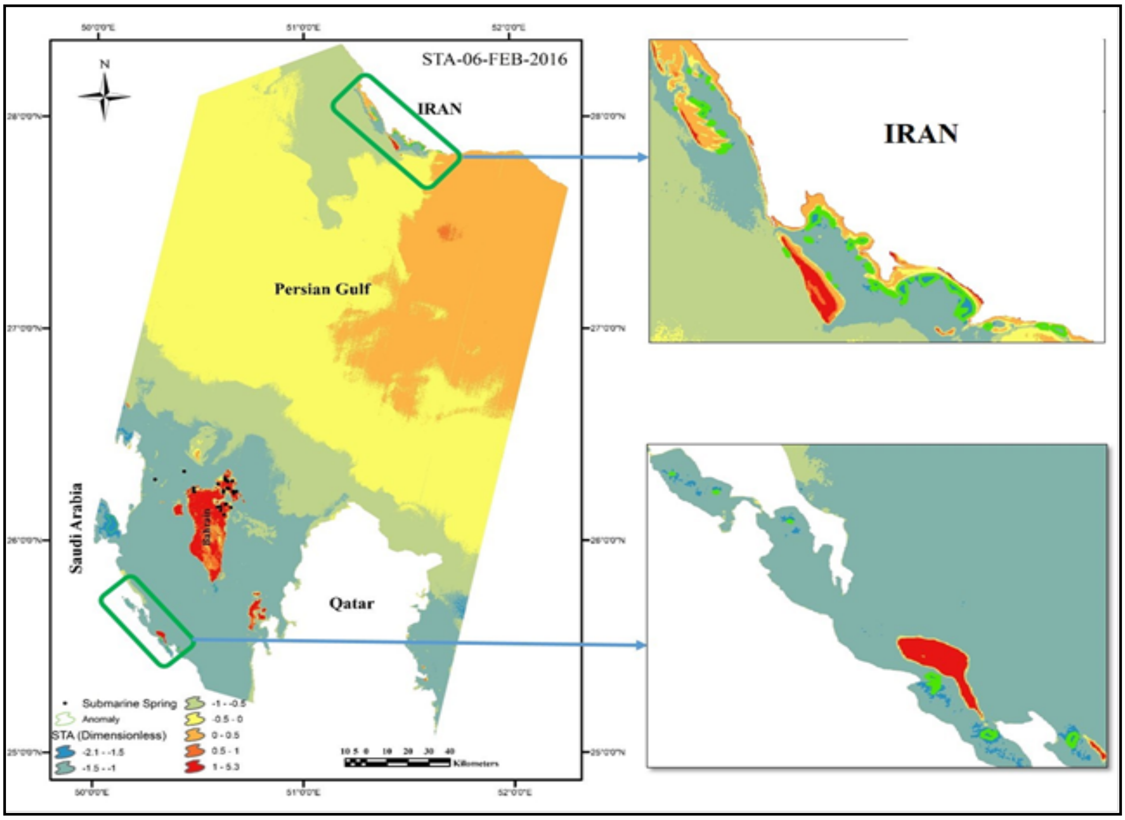

Figure 2. STA Map based on 06-FEB-2016 data with anomalies boundary and the location of springs.

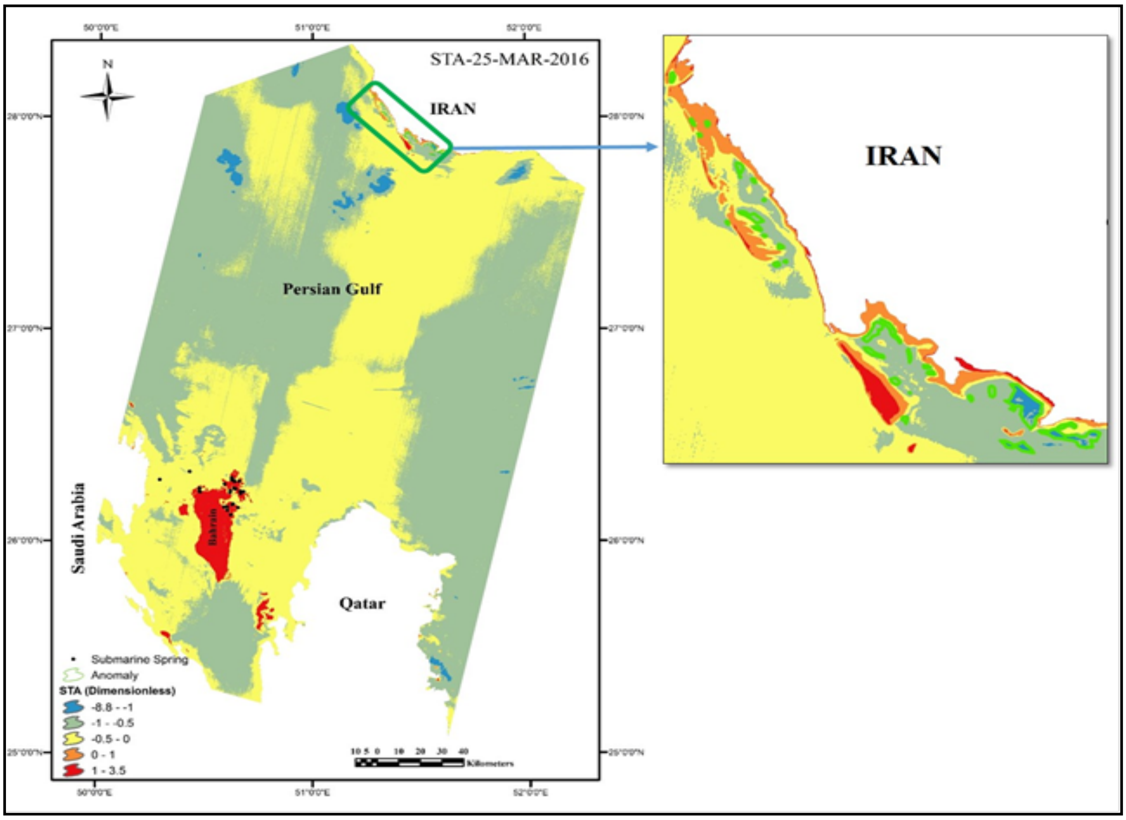

Figure 3. STA Map based on 25-MAR-2016 with anomalies boundary and the spring sites.

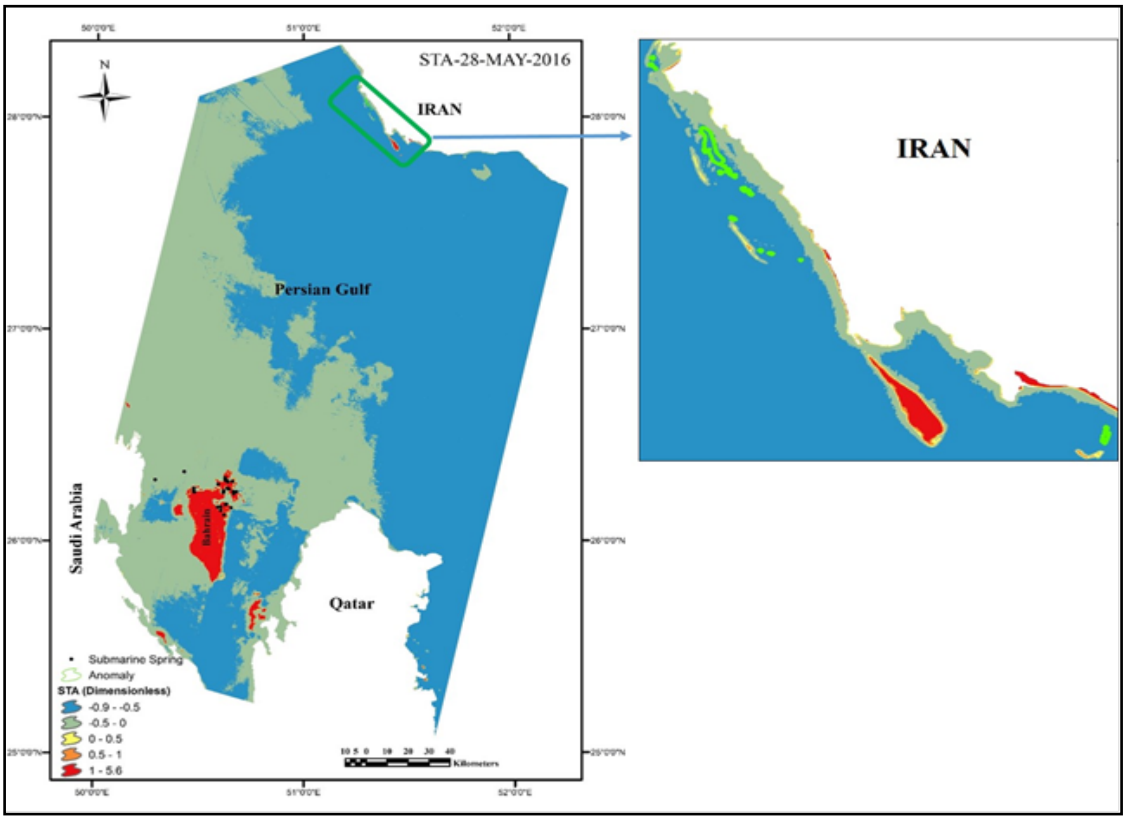

Figure 4. STA Map based on 28-MAY-2016 with anomalies boundary and the location of springs.

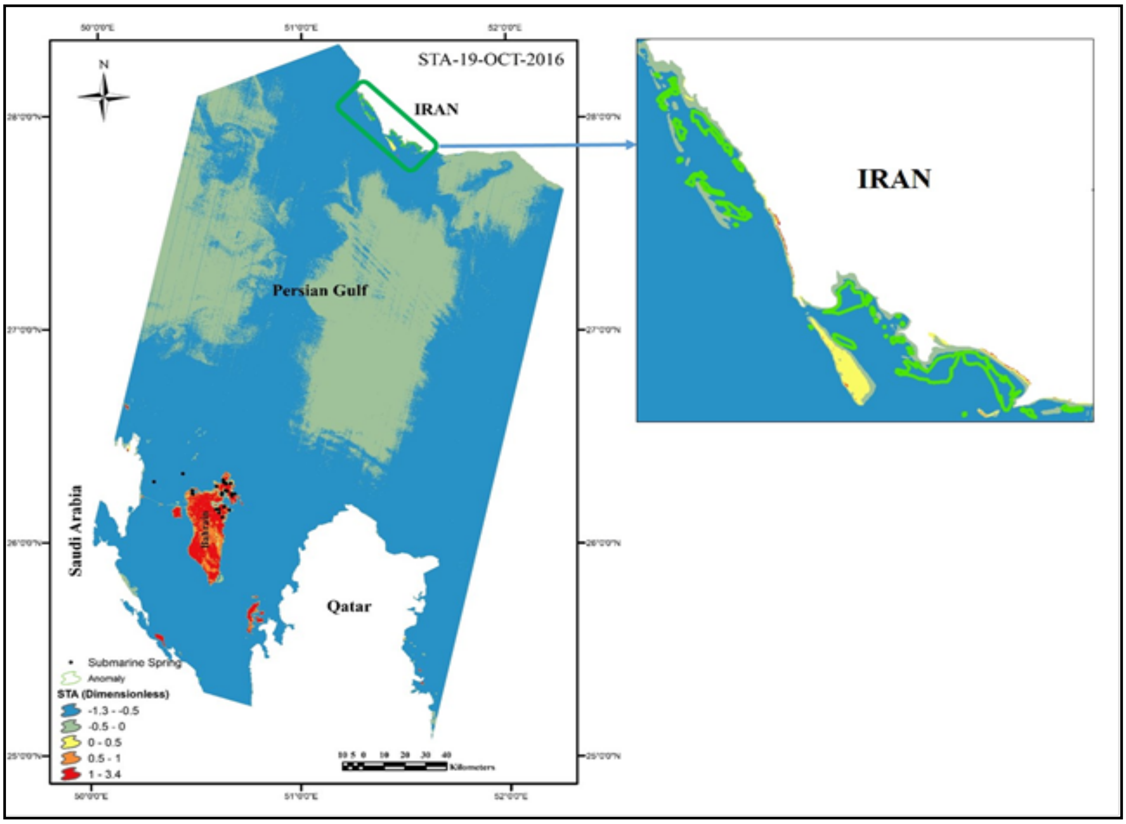

Figure 5. STA Map based on 19-OCT-2016 data with anomalies boundary and the location of springs.

It has been stated that estimation of groundwater discharge into Persian Gulf using traditional techniques including seepage meters and piezometers is problematic because the flow is often patchy and diffuse (Lee and Cherry, 1978). The artesian springs are the first report on seepage into the Persian Gulf (Judd and Hovland, 2007). Willams (1946) and Fromant (1965) have reported freshwater discharge from narrow fractures into the shallow sea around Bahrain islands (south of the Persian Gulf). It is reported that Bahraini pearl-fishers could survive on the sea for long times by collecting freshwater from submarine springs (Chapman, 1981). There are 29 submarine freshwater springs in Bahrain's water (Al Bassam and Toro, 2011); Umm Jarajir is the most important spring with 10 meter depth. Total discharge rate of this specific spring has not been studied as yet, nevertheless it seems to discharge a substantial volume of the water. Despite the very high potential of SGD into northern coastlines than the southern coastlines of the Persian Gulf including more rain, presence of significant Karstic formations in nearby, several faults and lineaments, etc., there are no reports or scientific article about this region as yet. Hence, we have tried to demonstrate the importance of northern coastlines of the Persian Gulf in presenting probable SGD using thermal remote sensing at moderate resolution.

As can be seen from figures 2 to 5, in spite of presence of 29 submarine freshwater springs around Bahrain (south of the Persian Gulf), thermal anomalies on northern coastlines of the Persian Gulf are much more than the southern coastlines so that considerable anomaly was not detected around and near Bahrain.

4. CONCLUSION

The anomalies show the localized abrupt changes or discontinuities that result from disturbance events that we believe this events on coastlines of the Persian Gulf are related to SGD. In addition, the lands leading to the northern coastlines have different conditions from the other side of the Persian Gulf including more rain, more suitable geological settings, and steeper hydraulic gradient that are prone to appearance of submarine springs on the northern coastlines than the southern coastlines. Therefore, we can conclude that most probably the rate of SGD in north of the Persian Gulf is very high and much more than the south. So, the coastal aquifers may have active interactions with the sea in this regions that may significantly impact water chemistry, water quality, biology and ecology; which, unfortunately, has been ignored as yet. This approach can be used for any coastal regions that may have an interaction with coastal aquifers especially on the other Persian Gulf coastlines.

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