Prof .Dr. Abdul Aziz Al Bassam
Professor of Hydrogeology/Faculty of Science/King Saud University
Eng. Hiba Mohammed Tiro
GIS Department Manager / Engineering Department / Saudi Oger LTD

"Using Remote Sensing and GIS for Submarine freshwater Springs exploration as a Plausible water source in Saudi Arabia"

C O N T E N T S

Abstracts

GIS and Remote Sensing are powerful tools which provide solutions for water resources problems; such as assessing water quality, determining water availability, managing flood problems, understanding the natural environment, and managing water resources on local and regional levels.

Coastal aquifers have the tendency to discharge their subsurface flow into the sea either through seepage or submarine springs where fractures prevail. Karstic aquifers may have hydraulic links with the sea resulting in dominant flow of submarine springs. These springs were known to exist since the time of the Phoenicians (1000 years ago) where they used submarine springs. Recently submarine springs were discovered by divers and described by scientists in many countries such as Greece, France, Libya, Italy, Spain and South America and some other areas in the world. Submarine springs are known to occur in Saudi Arabia on both the eastern coastal area (Arabian Gulf) and the western coastal area (Red Sea). Although these springs are well documented no attempts were made to survey these areas in order to locate these springs.

This paper aims at describing the practical implementation of Geographic Information Systems (GIS) and Remote Sensing to investigate the location of submarine springs in the coastal areas of Saudi Arabia (both eastern and western) using thermal infrared band of landsat images. This technique will involve the use of Landsat 7 enhanced thematic mapper, visible and near infrared band of 30 m resolution, A general overview for both coastal areas will be looked at to delineate clusters of freshwater springs. The determination of the selected locations will be based on the geological background of Saudi Arabia and the preliminary assessment of landsat images.

Key Words: Submarine springs, GIS, Landsat, Coastal Area, aquifers.

1. *Introduction, Problematic And Objective:*

- **Presence and Hydrogeology of Submarine Springs**

The presence of submarine spring water is a common phenomenon in the continental shelf areas around the world. Recently submarine springs were discovered by divers and described by scientists in many countries such as Greece, France, Libya, Italy, Spain and South America and some other areas in the world.

Submarine springs which are a result of the submarine groundwater discharge (SGD) is a coastal process that is driven by a composite of climatologic, hydrogeologic, and oceanographic processes.

A basic driver of freshwater SGD is the amount of rainfall received by the drainage basin, coupled with evapo-transpiration rates and the surface geology (particularly the surface infiltration capacity) but flow through coastal marine sediments can occur for a variety of reasons. Flow may be induced by the terrestrial hydraulic gradient as well as by marine processes such as wave set-up, tidally driven oscillations, density-driven convection, and thermal convection.

The mix will be different in different regions. It will depend, for example, on the hydraulic conductivity, hydraulic head, groundwater catchment area, recharge rates and many other factors. Density-coupled modeling of the saltwater interface indicates that seawater recirculation rates of 60% and more can occur due to dispersion and mixing within the aquifer even when wave and tidal effects are ignored. Since wave-induced and tidal effects are rarely completely absent, a great deal of seawater recirculation must occur on a global scale, while the local effects of freshwater SGD can be dominant in near shore environments.

Coastal aquifers have the tendency to discharge their subsurface flow into the sea either through seepage or submarine springs where fractures prevail. Karstic aquifers may have hydraulic links with the sea resulting in dominant flow of submarine springs. Submarine springs are known to occur in Saudi Arabia on both the eastern coastal area (Arabian Gulf) and the western coastal area (Red Sea).

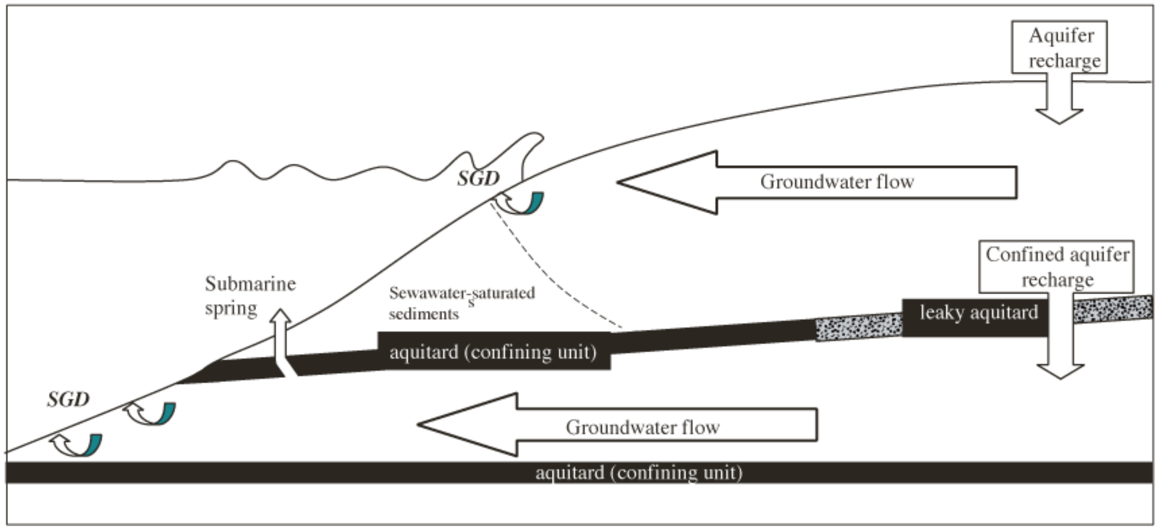


Figure 1 - Submarine Groundwater Discharge

Remote sensing refers to the process of gathering information about an object, at a distance, without touching the object itself. The most common remote sensing method that comes to most people's minds is the photographic image of an object taken with a camera. Remote sensing has evolved into much more than looking at objects with our eyes. It now includes using instruments, which can measure attributes about objects which unaided human eyes can't see or sense. Some other definitions of Remote Sensing are:
Remote Sensing is the art, science and technology of obtaining reliable information about physical objects and the environment, through a process of recording, measuring and interpreting imagery and digital representations of energy patterns derived from noncontact sensor systems" (Colwell, 1997).

"Remote sensing may be broadly defined as the collection of information about an object without being in physical contact with the object. Aircraft and satellites are the common platforms from which remote sensing observations are made. The term remote sensing is restricted to methods that employ electromagnetic energy as the means of detecting and measuring target characteristics" (Sabins, 1998).

- **<u>Principle of remote sensing</u>**

Generally, remote sensing refers to the activities of recording/observing/perceiving (sensing) objects or events at far away (remote) places. In remote sensing, the sensors are not in direct contact with the objects or events being observed. The information needs a physical carrier to travel from the objects/events to the sensors through an intervening medium. **Figure (2).**

The electromagnetic radiation is normally used as an information carrier in remote sensing. The output of a remote sensing system is usually an image representing the scene being observed. A further step of image analysis and interpretation is required in order to extract useful information from the image. The human visual system is an example of a remote sensing system in this general sense.

The Electromagnetic radiation has two fields: An electrical field & Magnetic field (**Figure 3, 4, 5**),

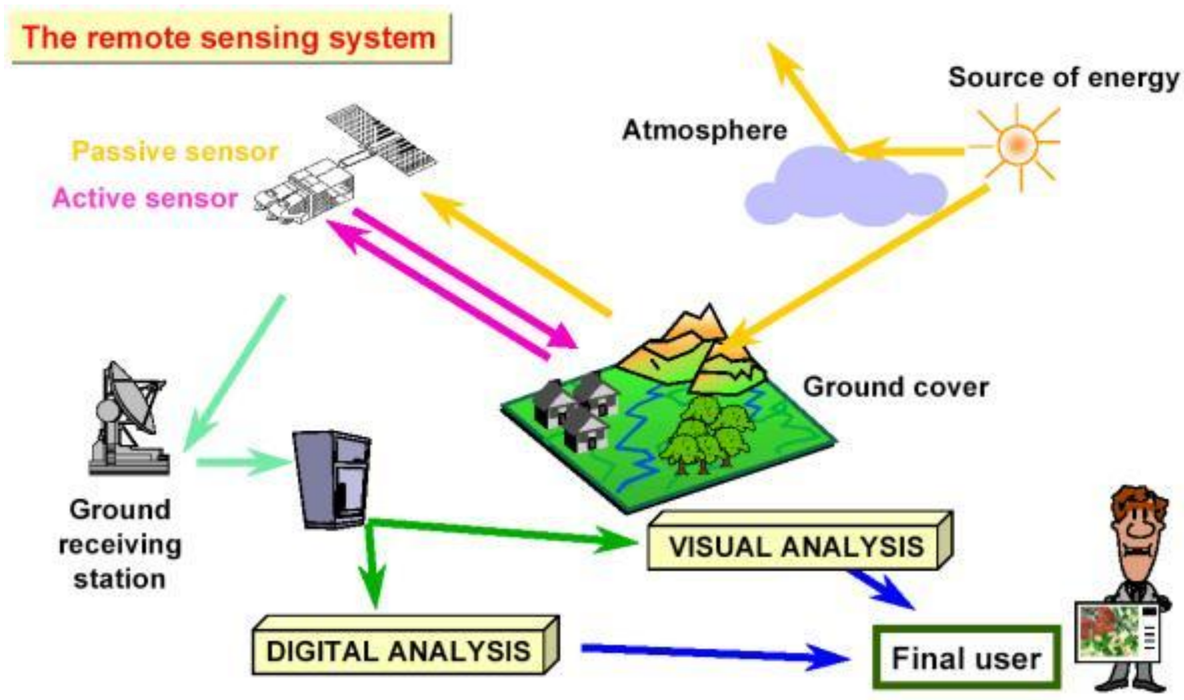


Figure 2- Remote Sensing system

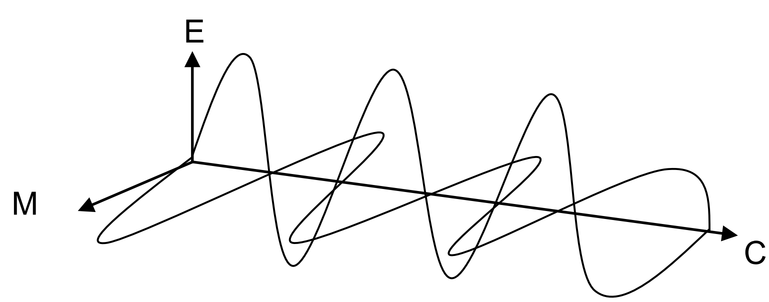


Figure 3- Electromagnetic radiation

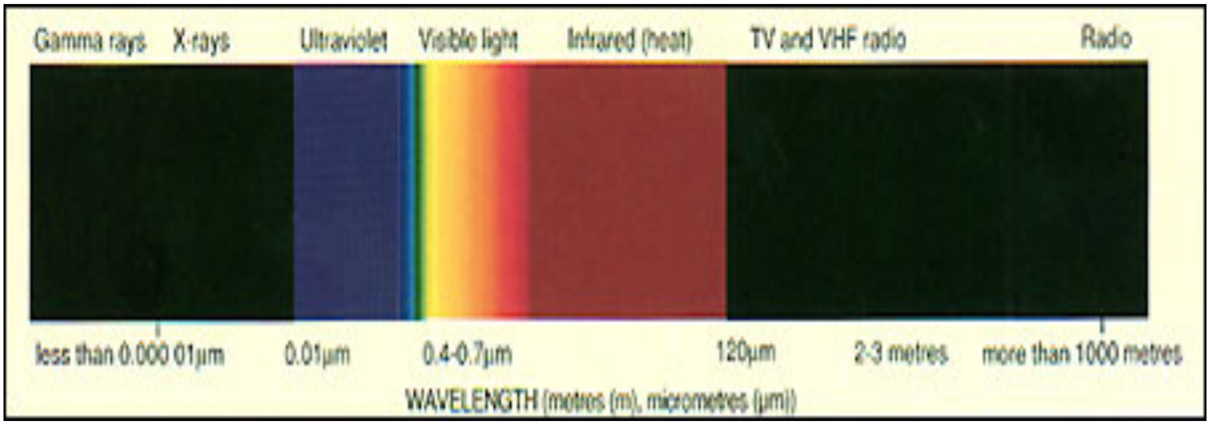


Figure 4- Electromagnetic Spectrum

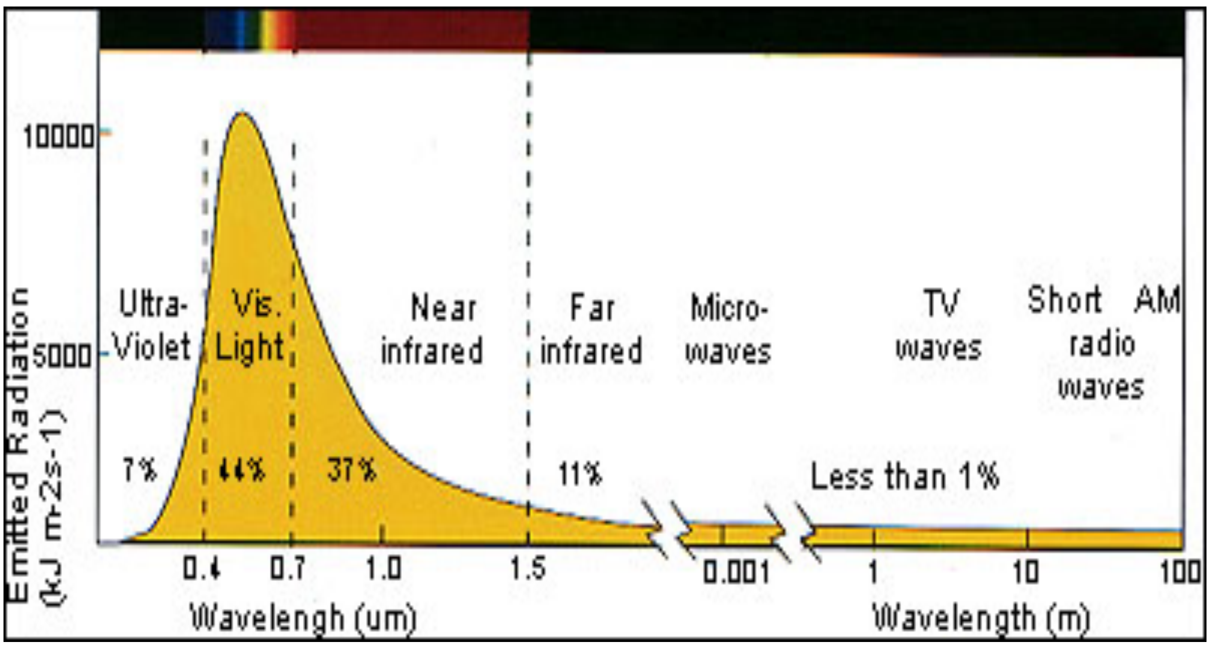


Figure 5-The Sun

The sun sends its radiation to the earth through the atmosphere as electromagnetic waves.
This occurs during day time however, at night the earth dark body emits the surplus of energy back to the atmosphere, the black body emission spectrum for planet Earth can be calculated assuming, for example, an average temperature for Earth and atmosphere of 250 Kelvin.

The relation between the emitted radiation and the wave length are shown in figure 6 illustrates the fact that the cooler a body, the longer the wavelength of peak emission and of the emitted energy overall. Therefore, the cold bodies emit less energy.

Each target on the earth surface has its spectral reflection which is related to its energy.

λ= 3000/T (Mm)

Where:
T=the target temperature /Kelvin
λ =the wave length/m

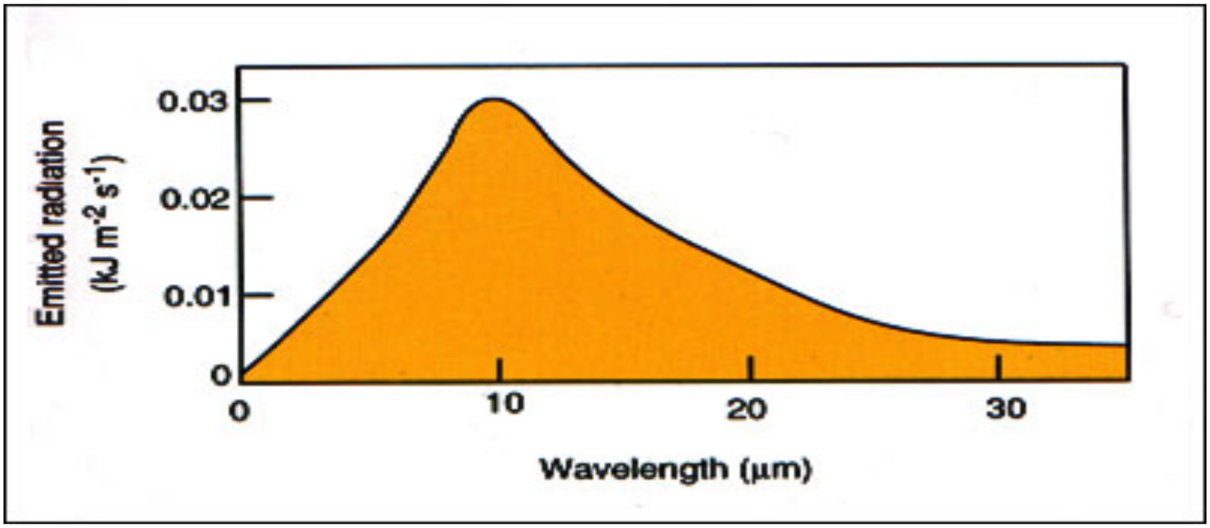


Figure 6-The Earth

Wavelength of energy recorded by the sensor/s

When sunlight falls on a surface some energy is reflected, some is absorbed and some is transmitted. Sunlight consists of many different wavelengths. The physical and chemical properties of Earth surface materials affect the amount of energy reflected, absorbed or transmitted. Natural surfaces are like filters selectively reflecting, absorbing or transmitting energy according to their wavelengths.

- **Types of sensors**

Another attribute of remote sensors, relates to the mode in which those that move along some track (orbit or flight path) to gather their data. In doing so, they are said to scan the path covering an area to the side known as the *swath width*, as determined by its angular FOV. Hence we can classify two types of sensors:

The **Whiskbroom**, and the **Pushbroom** type. In addition sensors can be classified with respect to the measured wave length. The later are called bands (**figure 7&8)**
The most important band for our study is band 6 (thermal band).

Thermal sensors

Many multispectral (MSS) systems sense radiation in the thermal infrared as well as the visible and reflected infrared portions of the spectrum. However, remote sensing of energy emitted from the Earth's surface in the thermal infrared (3 mm to 15 mm) is different than the sensing of reflected energy. Thermal sensors use photo detectors sensitive to the direct contact of photons on their surface, to detect emitted thermal radiation. The detectors are cooled to temperatures close to absolute zero in order to limit their own thermal emissions. Thermal sensors essentially measure the surface temperature and thermal properties of targets. Because of the relatively long wavelength of thermal radiation (compared to visible radiation), atmospheric scattering is minimal. However, absorption by atmospheric gases normally restricts thermal sensing to two specific regions - 3 to 5 μm and 8 to 14 μm. Because energy decreases as the wavelength increases, thermal sensors generally have large IFOVs to ensure that enough energy reaches the detector in order to make a reliable measurement. Therefore the spatial resolution of thermal sensors is usually fairly coarse, relative to the spatial resolution possible in the visible and reflected infrared. Thermal imagery can be acquired during the day or night (because the radiation is emitted not reflected) and is used for a variety of applications such as military reconnaissance, disaster management (forest fire mapping), and heat loss monitoring.

Landsat 7 Characteristics

Spectral sensitivity of Landsat 7 Bands.

Band Number	Wavelength Interval	Spectral Response	Ground Resolution(m)
1	0.45-0.52 μm	Blue-Green	30
2	0.52-0.60 μm	Green	30
3	0.63-0.69 μm	Red	30
4	0.76-0.90 μm	Near IR	30
5	1.55-1.75 μm	Mid-IR	30
6	10.40-12.50 μm	Thermal IR	60
7	2.08-2.35 μm	Mid-IR	30

Figure 7-Landsat Characteristic

	Band Application
1	**coastal water mapping, soil/vegetation discrimination, forest classification, man-made feature identification**
2	vegetation discrimination and health monitoring, man-made feature identification
3	plant species identification, man-made feature identification
4	soil moisture monitoring, vegetation monitoring, water body discrimination
5	vegetation moisture content monitoring
6	surface temperature, vegetation stress monitoring, soil moisture monitoring, cloud differentiation, volcanic monitoring
7	mineral and rock discrimination, vegetation moisture content

Figure 8-Landsat applications

The primary new features on Landsat 7 are:

- a panchromatic band with 15m spatial resolution
- on board, full aperture, 5% absolute radiometric calibration
- a thermal IR channel with 60m spatial resolution

The Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) sensors acquire temperature data and store this information as a digital number (DN) with a range between 0 and 255. It is possible to convert these DNs to degrees Kelvin using a two step process. The first step is to convert the DNs to radiance values using the bias and gain values specific to the individual scene you are working with. The second step converts the radiance data to degrees Kelvin.

- **Detecting Submarine Springs Using TIR**

Thermal Infrared Imagery is an effective way of identifying submarine springs. This technique is based on the pronounced thermal gradient between the groundwater and ambient surface conditions. The thermal infrared Imagery is an effective method to quickly assess large-scale areas and acquire information about specific locations of groundwater discharge.

The groundwater temperature is relatively stable and it is as an average temperature of the area, while the temperatures of the surface water are changeable with changing the seasons. Thermal infrared only measures surface temperatures so its application is limited to the surface seawater.

Since the 1970s, both satellite and airborne TIR have been used to detect groundwater discharge, either warmer or cooler than the surrounding surface water, by successfully detecting the contrast in water temperature from different sources.

Unlike reflected energy, thermal infrared sensors measure the energy emitted from objects in the thermal infrared region of the spectrum, with wavelengths that fall between those of visible light and microwave. Use of a TIR sensor during the day presents a complex set of issues associated with sunlight, including air temperature, solar gain (increased energy from objects absorbing solar energy), and temperature differences associated with aspect and shadow.

The optimal time for groundwater TIR application is at night, preferably in predawn hours, when the temperatures of surface features are lowest During this time, landscape features will display greater contrast with surface water and unique thermal features such as seeps. The acquisition of thermal infrared imagery during the predawn hours ensures that most materials, including water, have released stored energy and have reached a state of equilibrium with the surrounding air temperature. Additionally, image acquisition during cold weather ensures that less heating occurred during the day and surface features quickly reach equilibrium with colder air temperatures at night.

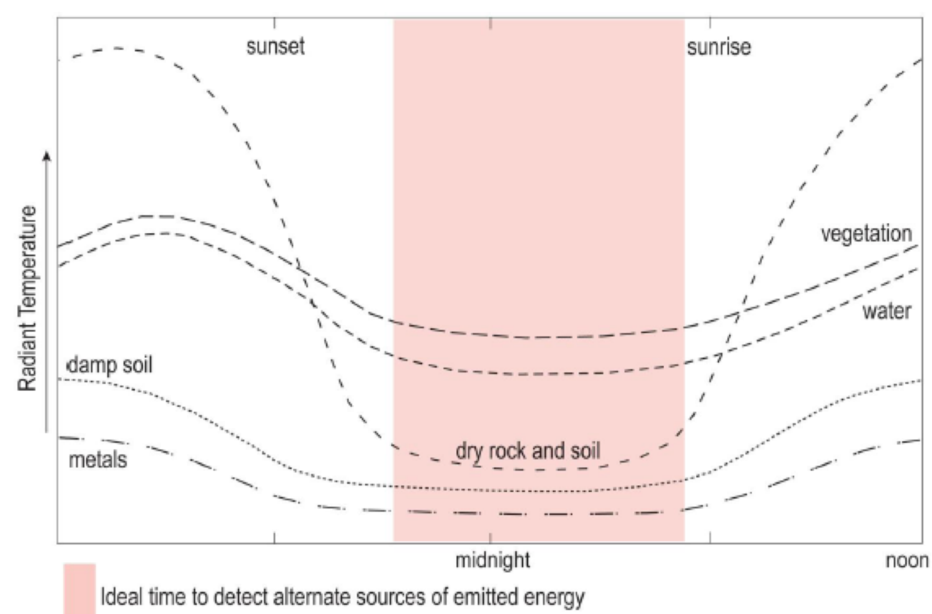


Figure 9- Diurnal cycle of heating and cooling

Researches using thermal infrared imaging in the Dead Sea have shown that the sea water temperature varies from 20-21 degree C, whereas the submarine springs temperature varies from 26-35 degree C depending on the area.

Objectives of the current study

Following are the main objectives of the study.

- To identify the thermal (Land Sat 7) characteristics for areas of know, identified and measured submarine springs
- To apply the same characteristics to other areas in order to identify the presenceof submarine springs

2. *Study Area:*

Our study was based on two areas,

First area **(figure 10)** is located on the red sea, south of Saudi Arabia, close to the border with Yemen, where the geological, topographical and hydrological settings support the presences of submarine springs. The presence of Tihama mountain range with the highest annual rainfall average in the area with many wadis flowing towards the west (the coastal plain), where it infiltrates down to the alluvial aquifers. The infiltrated water flows as underground water to finally discharge in the Red Sea. No attempt was made to investigate the presence of these submarine springs. However the water authority sensed that water is lost to the sea, for that reason subsurface dams were constructed or planned to be constructed. A need was raised to evaluate the presence of submarine springs and their discharge.

Second area **(figure 11)** is located in the Arab gulf, east of Saudi Arabia, very close to Bahrian where submarine springs are historically known to present. Pearl seeking divers described the presence of these features and used to get supply of freshwater from them. In 1976 a study was initiated by the Ministry of agriculture and water (MAW) to study water resources in Bahrain. Professional scientists and divers went down to locate these springs and map them. They identified at least 27 springs. (Figure 12)The identified spring were used in the current study to know the thermal characteristics of the area as affected by the springs.

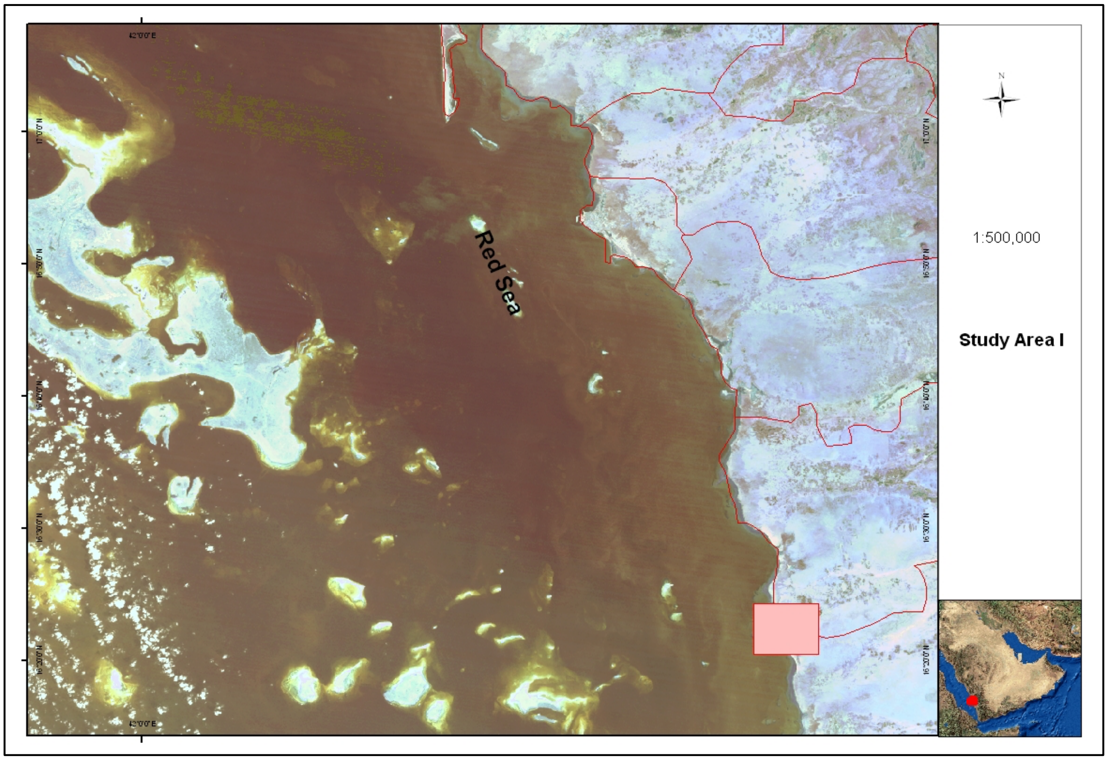


Figure 10: study area I

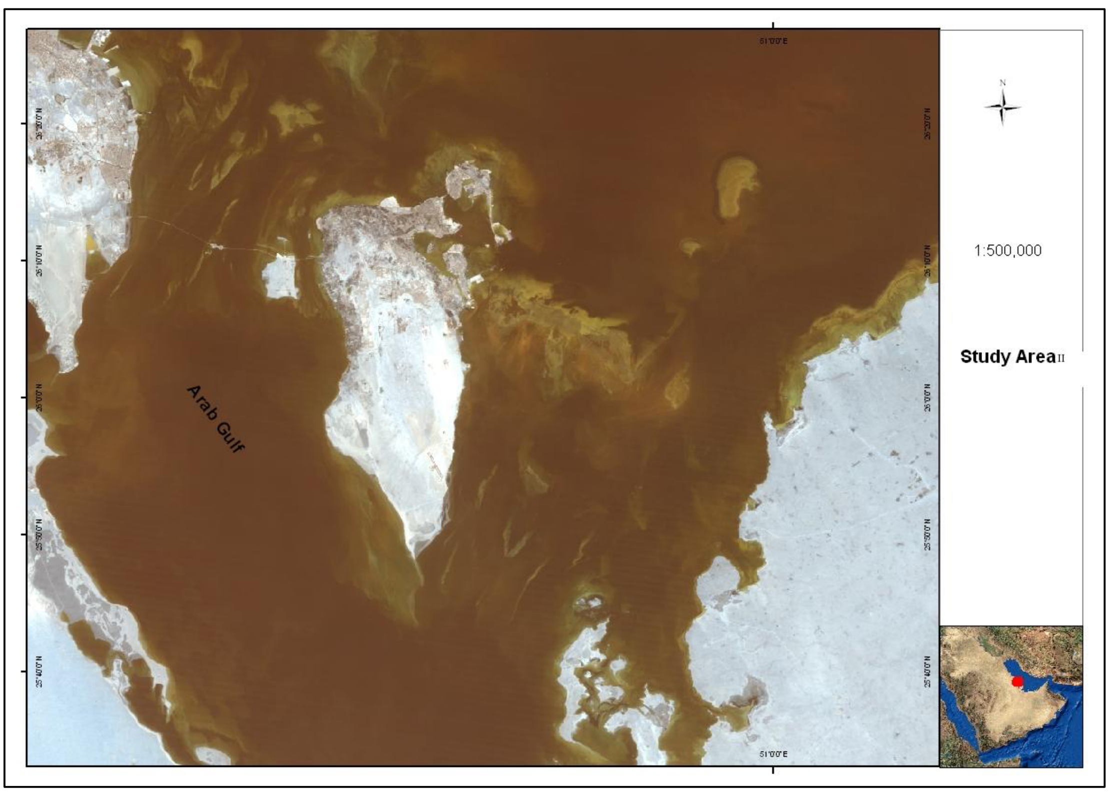


Figure 11: study area II

3. *Martial And Methodology :*

GIS & Remote sensing were used in the development of input data set for a conceptual converting DNs to degrees Kelvin. The entire data was analyzed in the PC ARC/INFO (ver 9.3) GIS domain, ERDAS Imagine 9.1, and Landsat TM (30) m was the only input data used to extract the necessary information.

Our methodology:

Converting Landsat-7 thermal band digital value to temperature

We used calculate function to convert Temperature reading from digital value to Celsius.

(1282.71/((666.09/ ((((12.65-3.2)/255) *[Value]) +3.2))+1).ln)-273

Conversion to Radiance

During first phase, image pixels are converted to units of absolute radiance using the following equation:

Radiance = gain * DN + offset

This is also expressed as:

$$\textbf{Radiance} = ((L_{MAX}-L_{MIN})/(QCAL_{MAX}-QCAL_{MIN})) * (QCAL-QCAL_{MIN}) + L_{MIN}$$

where: $QCAL_{MIN}$ = 1 (LPGS Products)
= 0 (NLAPS Products)

$QCAL_{MAX}$ = 255

QCAL = Digital Number

Convert Radiance to Kelvin:

Once the DNs for the thermal bands have been converted to radiance values, it is simply a matter of applying the inverse of the Planck function to derive temperature values.
The formula to convert radiance to temperature:

$$T = \frac{K_2}{\ln\left(\frac{K_1}{CV_R} + 1\right)}$$

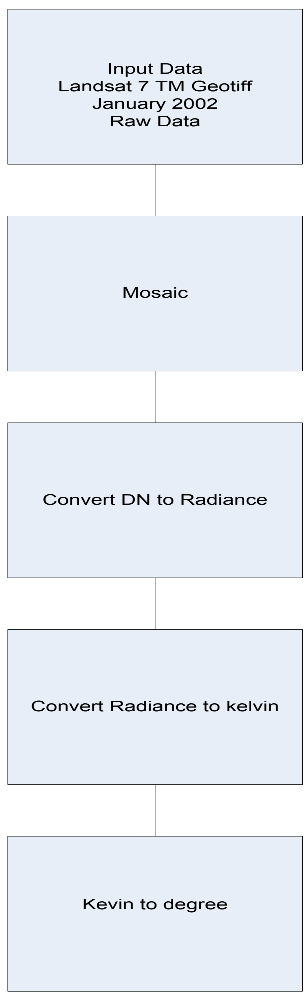
Where:

T is degrees Kelvin

CV_R is the cell value as radiance

K_1 is 607.76 (for TM) or 666.09 (for ETM+)

K_2 is 1260.56 (for TM) or 1282.71 (for ETM+



An excel table about submarine location in study area II was converted into shp file and applied on the second study area.

Spring Name	Geographical Coordinates						Spring Levels (m.amsl)
	Latitude			Longitude			
	Degree	Minute	Seconds	Degree	Minute	Seconds	
Kawkab Salih	26	9	43.2	50	35	21.5	-1.5
Umm As Sawali	26	13	31.4	50	39	56.5	-1.6
Kawkab Qaryah	26	9	46.8	50	36	13	0
Umm Jarajir	26	13	49.2	50	36	59.9	-10
Causeway Spring	26	9	31.9	50	39	11.4	-4
Jurdi Spring 4a	26	17	0.7	50	39	35.9	-1.2
Jurdi Spring 4b	26	17	2.2	50	39	36.3	-1.2
Abu Mahir	26	14	20.2	50	37	6	-1.7
Kawkab Ma'amir	26	7	30.1	50	37	11.8	-0.7
Ayn Shuraybah	26	15	2.3	50	28	32	-1.7
Al Ayaee	26	14	4.9	50	40	50.2	-3
Kawkab Al Akr	26	8	47.9	50	36	16.1	0.4
Sitrah Halat	26	10	23.9	50	37	39.1	-0.8
Khawr Fasht	26	19	43.9	50	25	46	-2.1
North Sitrah	26	10	35.6	50	37	51.7	-0.6
Bu Kalem	26	14	10.7	50	39	52.8	-1.2
As Saya	26	16	14.5	50	35	30.6	-0.4
Al Fuara	26	13	59.6	50	28	40.3	0.5
Shuraybah Safli	26	14	8.8	50	28	29.8	-0.9
Awayda	26	18	1.6	50	37	29.5	-1.2
Arad School	26	14	52.2	50	38	33.6	0.4
Kawkab Wusthi 9a	26	16	54	50	38	16.7	0.1
Ain Jalib 9b	26	16	54.9	50	38	16	0.2
Ain Jalib 9c	26	17	4.1	50	38	12.5	0
Kawkab Shamali 9d	26	17	5.2	50	38	9.3	0.2
Arad Fort	26	15	3.6	50	38	7.2	0.5
Kawkab Khsayfah 6a	26	17	26.1	50	17	25.3	-0.3
Ab Bad 6b	26	17	22.1	50	37	30	-0.4
Kawkab Rayya Al Hayour	26	17	18.1	50	37	53.7	-0.2

Figure 12: Submarine Location Table

4. Results and Discussion:

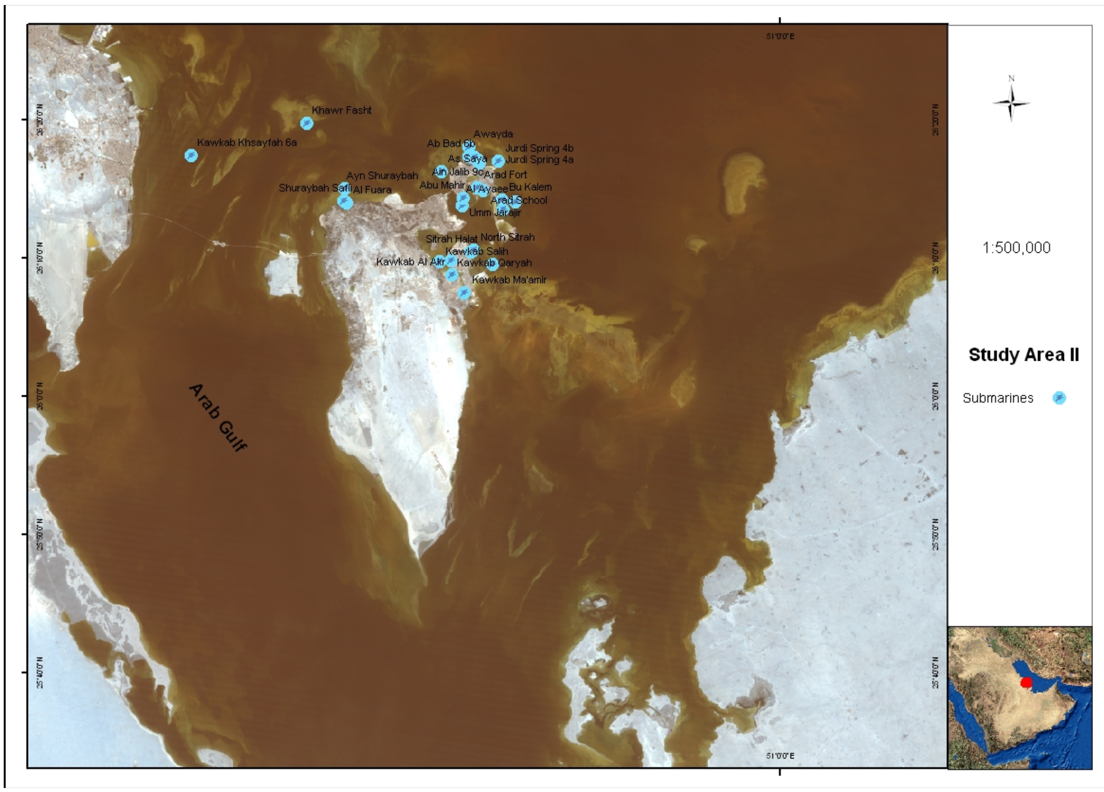
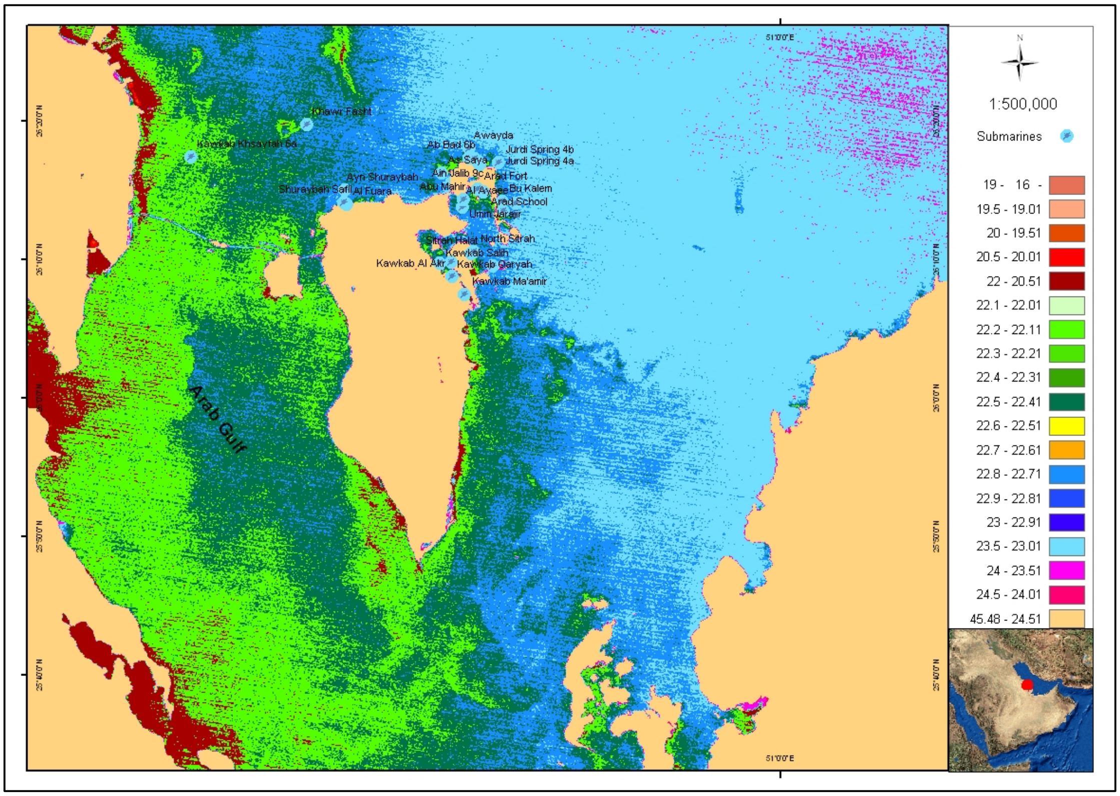


Figure 13: Some Submarine located in Arab Gulf



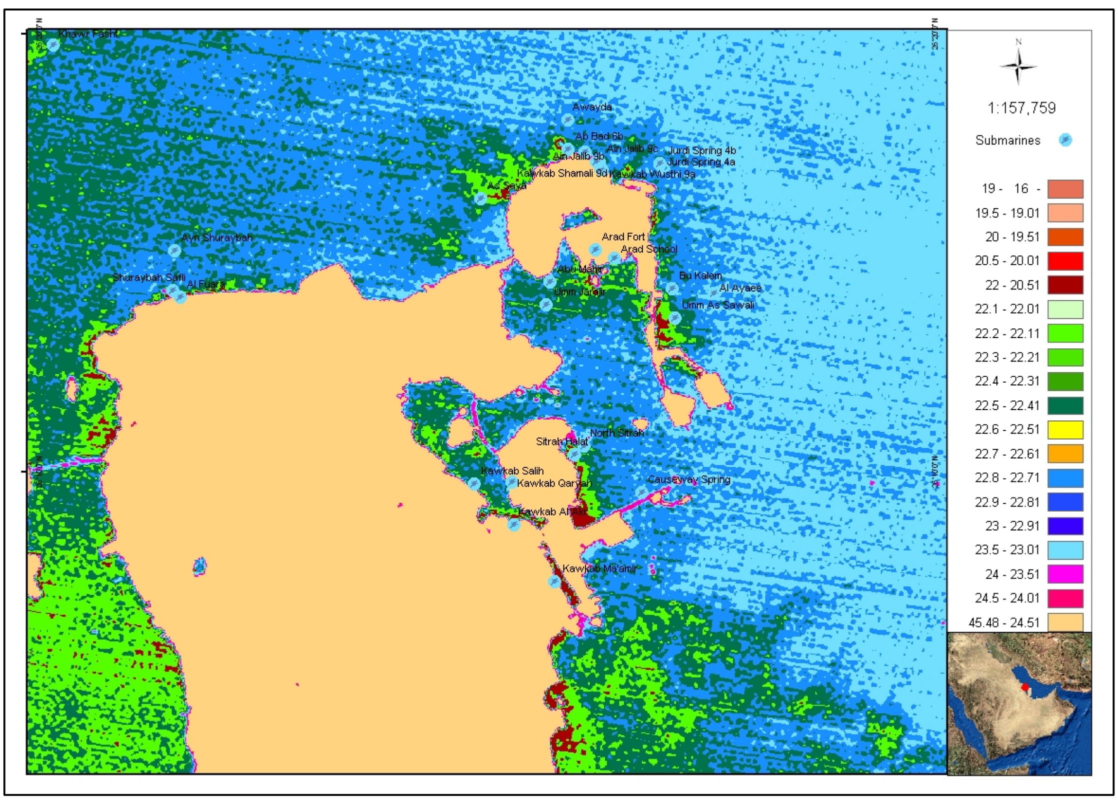
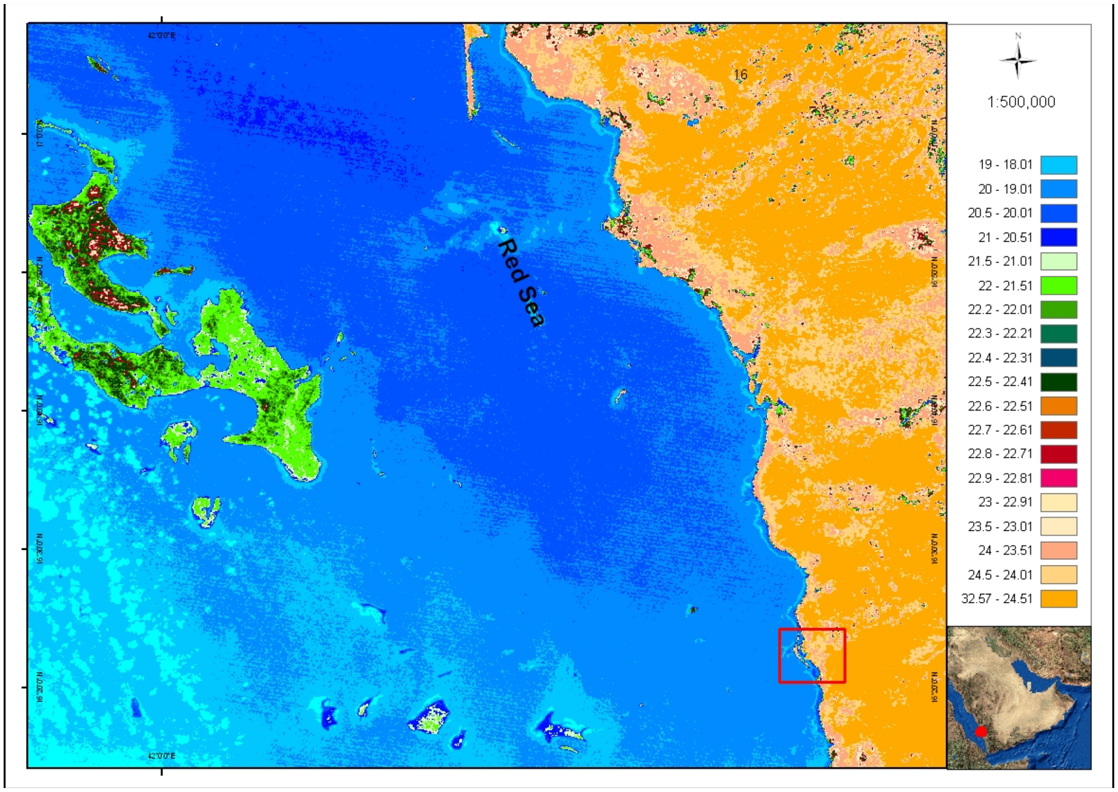


Figure 14 & 15 –Study Area 2 Temperature image Classification



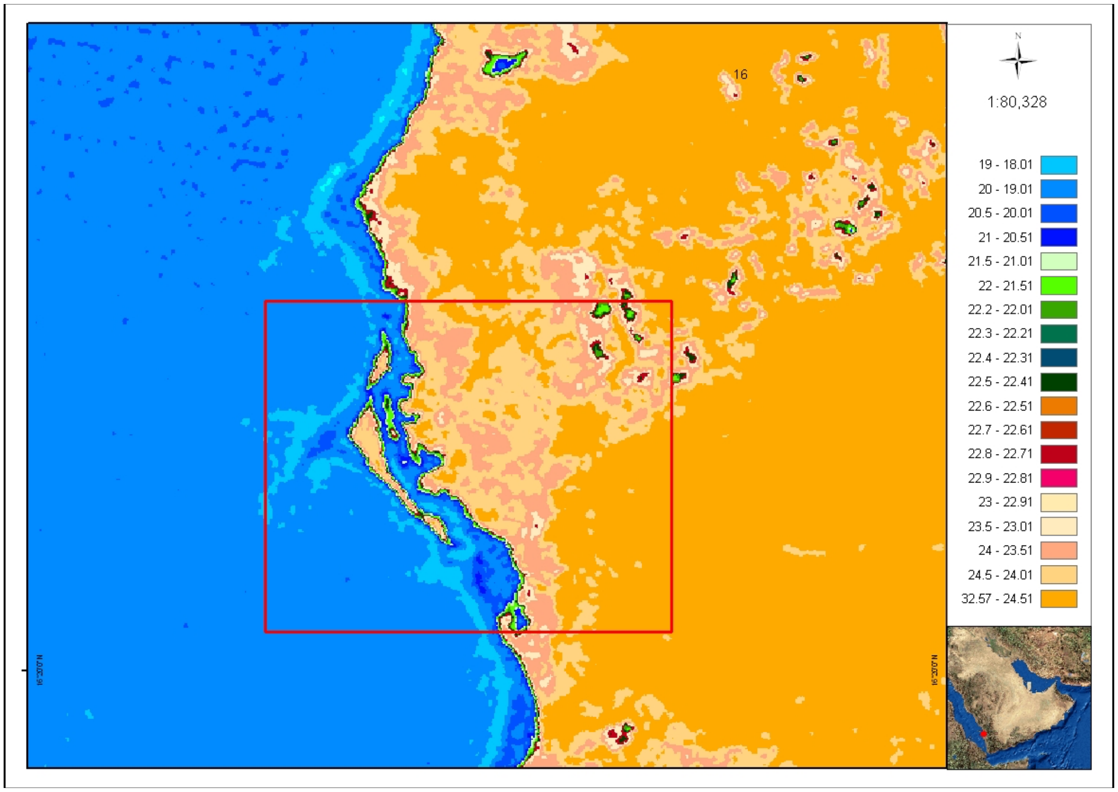


Figure 16 & 17 –Study Area 1 Temperature image Classification

As mentioned earlier there are around 27 known, visited, and located submarine springs in the Arabian Gulf. In the current study, the springs were used as an indicator to determine the thermal characteristics of their presence. The springs were plotted on the thermal image. Thermal signals indicted that the temperature of the spring spots fall between 22.1 and 22.5. Of course these temperatures do not exactly reflect the spring water temperature. It was used merely as an indicator. On the other side of the country a search was made to find the same signals and temperatures by analogy and not by actual temperatures. The area shown on figure (16 & 17) is thought to have submarine springs. This is supported by the presence of major wadi discharging water to the sea both in the surface and subsurface.

5. *Suggestions and Recommendation :*

The problem of using Land Sat 7 for such study is the large resolution of their images. However the use of these images along with good knowledge of the geology, topography and hydrology may reveal a good possibility of detecting submarine spring. This must be coupled with field investigation and air borne TIR survey.
Interception of freshwater before it reaches the sea is very important for such areas as Saudi Arabia, where it suffers lack of water supplies, Therefore, plans were made to construct subsurface dams to intercept the water before it flows to the sea.

6. *References*

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