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GROUNDWATER DISCHARGE DETECTION ALONG THE NORTHWESTERN COASTS OF THE QATAR PENINSULA USING AIRBORN THERMAL INFRARED IMAGERY.

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ABSTRACT

An airborne thermographic survey was carried out along the northwestern coasts of the state of Qatar in March 1980. The objective of the study was to detect possible sources of groundwater discharge into the sea. Infrared linescanning was successful in detecting thermal anomalies at a number of locations along these coasts. Several of the warmer anomalies have been identified as groundwater discharge. The volume of groundwater loss was estimated at four main locations and was found to range from 560 to 3730 m^3/day depending on the location.

INTRODUCTION

Airborn thermal infrared linescanning technology has found widespread application in detecting many types of phenomena which manifest themselves through a difference in surface temperature. Such phenomena are often not detectable by the human eye or conventional aerial photography.

The ability of thermal infrared technology to detect small temperature differences on the surface of water bodies has been explotted for the detection of groundwater discharges into lakes, rivers and coastal ocean waters. The ease of detection of groundwater discharged depends on the difference between the ambient water temperature and the temperature of the discharge. Studies in Hawii (Fisher, 1966 and Palmer, 1967), showed that submarine fresh-water spring could be detected and mapped at a number of coastal locations. Groundwater discharge has also been successfully identified 'along the Bay of Biscay, (Lavesque, 1971) and off the coast of New York's Long. Island (Pluhowski, 1972). Meteorological conditions, tides and sea currents make the detection of groundwater discharge in coastal environments quite difficult unless the groundwater flow has a large volume or a large temperature difference from the ambient marine environments. Difficulties associated with costal marine environments have been described by Williams and Fenandopulle (1972) in a study on the detection of groundwater seepage in Canary Islands.

In the state of Qatar, a critical shortage of water is the limiting factor in municipal, industrial and agricultural development. It is known that up to 70 mm of preciptation falls, and infiltrates into favourable overburden and bedrock. However, previously it was possible to determine to what extent this water was infiltrating to the sea and was therefore lost to human use, nor was it known where such losses might occur. The purpose of this work was to determine if and where significant groundwater discharge to the sea was taking place. Such discharges, if identified, would be related to the hydrogeological environment, and the quantities of water being lost could be calculated.

In order to maxmize the probability of detecting ground water, it was decided to undertake the aerial thermographic survey in the February to March period when the greatest possible differential would exist between the groundwater temperature and the ambient sea surface temperature. Sea surface temperatures, which are at a minimum at this time of year, were in the order of 22 degrees C (Persian Gulf Pilot, 1967) while the groundwater temperatures ranged from 30 to 35 degrees C.

DATA ACQUISITION

The thermal imagery was acquired with an AGA-634 infrared linescanner. The flightlines selected for the thermal survey are shown in Figure 1. All thermal infrared flights were carried out at an altitude iof 55.000 ft. above sea level, giving imagery with a scale approximately 1:20.000 along the flight line. The instantaneous field of view of the scanner was 1.7 milliradians.

DATA ANALYSIS

At the time of the airborne data collection, ground-water temperatures were in the order of 13°C higher than the sea surface temperature (Table 1). Thus, temperature anomalies associated with ground water discharge would appear warmer than the surrounding sea water temperatures. Likewise, colder anomalies would appear indicative of surface run-off from recent storms. Analysis of the thermal imegery indicated eight possible areas for ground water discharge which were located on a topographic map and identified by the name of the nearest village. The 70 mm photography of the region was also used to assist in the interpretation of the ground water discarge sites. From the eight areas thus identified, four occured in areas unsuitable for groundwater discharge. In addition, the anomalies in these four areas were explained, using photography, as being due to either man-made sources or tidal pools. The remaining four were identified as areas of potential natural groundwater discharge. These were (see Figure 1):

(1) Ras Ushayriq (2) Al Khuwayr
(3) Abu Az Zuluf (4) Ar Ruays

An example of the imagery for one off these areas is shown in Figure (2).

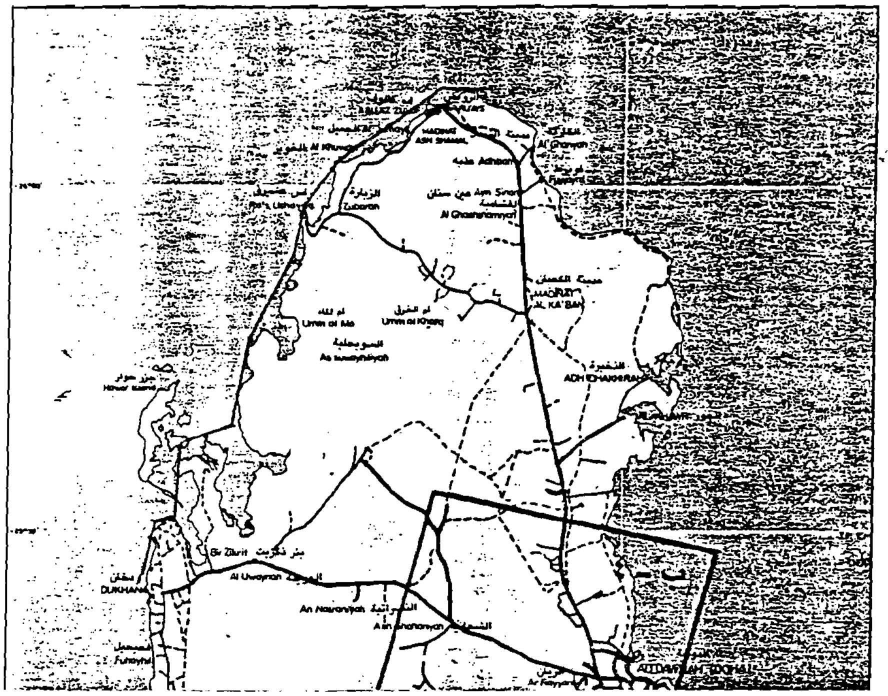

Fig. (1)

Location of thermal imagery observations.

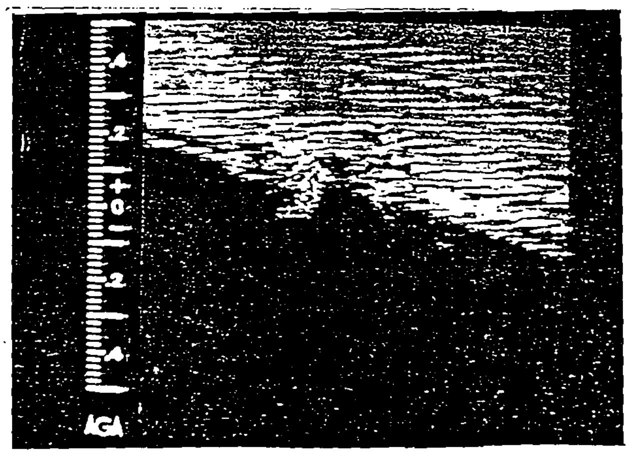

Fig. (2)
Colour infrared showing a fresh water dyke.

TABLE (1)

1980 Surface Truth Temperaturs (degrees c) northwestern coast of the Qatar Peninsula.

Date	Location	Local time	Paved road	Sand	Sea Surface	Fresh water	Groud water
Mar.14	Ras Ushayriq	1000	---	23.0	---	---	---
	Al-Khuwayr	1100	---	---	---	---	35.2
	Ab Az Zuluf	0510	--	19.4	---	---	---
	Ar Ruays	0525	21.4	20.6	22.6	20.5	---

All the potential groundwater discharge anomalies had similar physical characteristics. The temperature of these anomalies was about 5°C higher than the ambient sea surface temperature. The along shore dimensions were in the order of 1.5 km for each source and the warm anomalies were observed to extend to a width of 25 to 75 metres perpendicular to the coast. The discarges observed were all located in the vicinity of alluvial fans near the coast. At the seaward margin of the anomalies the sea water depth, estimated from the hydrographic charts, was 1 to 2 metres. It would thus appear that the fresh water discharge is seeping along the sea bottom perpendicular to the shore to a distance of between 25 and 75 metres.

In Ar Ruays area the discharge is probably derived from the alluvial fans of the Wadi (river). It is most likely due to water which inflitrated into the Wadi from the mountainous area to the east where considerable rainfall infiltration is known to occur.

In the area of Ras Ushayriq SW of Ruwis on the Gulf of Salwa, several anomalies were identified as groundwater discharges. It is possible that some of the groundwater seepage is from the leakage of irrigation water. However, the irrigation water was much colder than the groundwater, at the time of the over-fight (Table 1) and the observed temperature anomalies cannot therefore be explained by the leakage of irrigation water alone.

On March 14, thermal data was acquired on the northwestern coast of the peninsula between 0520 and 0750 local time and recorded on vedio tape; sunrise occured at 0629 on this day. The mission was flown in the early morning to minimize the effects of surface heating by the sun and to take advantage of low tide conditions.

In addition to the airborne data, surface temperatures of several different materials were measured at various locations along the northwestern coasts on the same day as each overflight. These materials included asphalt

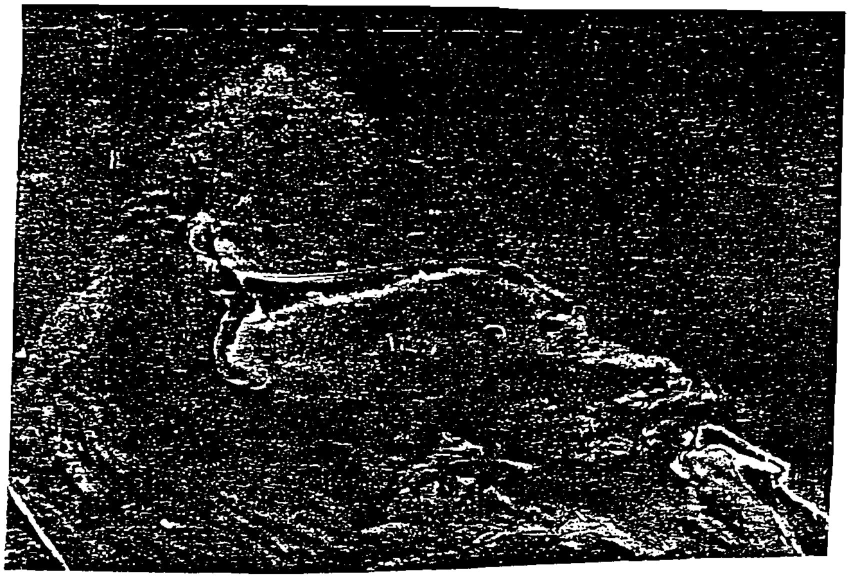

Fig. (3)
Infrared imagery showing thermal anomalies, west of Ar Ruays.

roads, soil, sand and sea water, etc. (Table 1). All temperatures were measured with a hand-held thermometer. Colour 70 mm photography at a scale of 1:1900 was also acquired during each flight as an aid to interpretation and track recovery.

The thermal data was processed to produce both analogue and level sliced imagery which was used for the analysis of the ground water discharge sits (Fig. 3).

The volumes of groundwater discharge into the sea was calculated for the Ras Ushayriq area on the Salwa Gulf coast, and for the Al Khuwayer, Abu Az Zuluf, Ar Ruays areas on these areas were considered to be the most important in terms of volume of groundwater discarge.

The thermograghic method was used to estimate the discharge. The thermographic method characterises the thermal anomaly by assuming that it consists of a perfectly mixed volume of sea and groundwater. The calculation assumes that the quantity of heat in a thermal anomaly per linear metre is equal to the sum of the heat in the sea water component at ambient temperature plus the heat in the groundwater portion. Thus, the heat balance in a linear metre of an anomaly is as follows:

$$(V - Qgw)\ Tsw + Qgw\ Tgw = VTa \quad ,$$

in which, V is the volume of the anomaly per linear metre, Qgw is the groundwater discharge per linear metre and Tsw, Tgw and Ta are the temperatures of the water, groundwater and the water in the anomaly. The volume V is calcaulated using the data on the width of the anomaly perpendicular to the shore (w) and the depth of the sea at the outer limit of the anomaly (d). For the areas under investigation values for W and Ta were obtained from the thermal imagery, d was estimated from hydrographic charts and Tsw and Tgw were obtained from ground measurements (see Table 1).

Using these data assuming that ground water discharge (Qgw) is replaced by the tide at a frequency of once per day, we can calculate the daily groundwater discharge per linear metre of shoreline. The length of the shoreline over which the anomalies occur was measured from the thermal imagery. Two measurements were made at each location. These were a minimum length over which the anomalies were clearly interpreted and an inferred length with the addition of areas where groundwater runoff appeared to be masked by surface water runoff from recent storms. The average of these two lengths is shown in Table 2 for each of the four areas. Recent measurements in the field (February - March 1980) has resulted in a more precise determination of the length of the shoreline where the anomalies occur. These lengths, determined by land and sea observations, are also shown in Table 2. It can be seen that there is reasonable agreement between the two data sets. The shoreline lengths used to calculate the results in Table 2 are the average lengths measured from the thermal imagery. The width of the anomaly (W) used in the calculations is an average value and was estimated from the thermal imagery to be 40 metres. If one takes into account the small variations in the width of the thermal anomalies, the estimate shown in Table 2 are slightly smaller in magnitude.

TABLE (2)

Length of shoreline (meters) over which anomalies were observed.

Area	Values obtained from thermal imagery			Ground Survey
	Minimum	Maximum	Average	measurements
Ras Ushayriq	600	1000	800	800
Al Khuwayr	620	2180	1400	1300
Abu Az Zuluf	700	1600	1150	800
Ar Ruays	560	1900	1230	800

CONCLUSIONS

Results of the data analysis permitted the author to make the following conclusions:

(1) Infrared linescanning was successful in providing a fast and inexpensive method for detecting thermal anomalies at a number of locations along the state of Qatar coasts. Several of the warmer anomalies have been identified as groundwater discharge. The colder anomalies appeared to be surface runoff resulting from a recent storm.
(2) All groundwater discharge occured at the shoreline/seawater interface. There was no evidence of any offshore springs.
(3) All the observed discharge areas located at the base of alluvial fans and along a major fractures.
(4) Groundwater loss in the four main tested areas was estimated as follows:

Ar Ruays	800 to 850 m^3/day
Abu Az Zuluf	820 to 3837 m^3/day
Al Khuwayr	480 to 2244 m^3/day
Ras Ushayriq	861 to 1411 m^3/day

Since all those areas studied involved groundwater discharge to the sea, groundwater development would be very sensitive to overpumping and resultant salt water intrusion into fresh water aquifers. Therefore, it would be useful to prepare mathematical models of aquifer behavior under varying pumping and recharge conditions. It would be possible to calculate, in advance, the safe yields of wells which would avoid salt water intrusion.

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