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CAPABILITIES/LIMITATIONS OF LANDSAT-TM DATA FOR BATHYMETRIC ANALYSIS OF SHALLOW MARINE ENVIRONMENT: A CASE STUDY.

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إمكانات وحدود إستخدام بيانات الماسح النوعي للقمر الصناعي «لاندسات» في تحليل الأعماق بالبيئة البحرية الضحلة : دراسة حالة

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إن شدة الضوء الذي تستقبله أجهزه الإستشعار بالقمر الصناعي «لاندسات» تتناسب عكسياً مع طول المسافة التي يقطعها الضوء خلال ماء البحر ، ونظراً لأن الضوء الساقط يصل إلى قاع البحر ثم يرتد منه إلى الجو فإن شدة الضوء المسجل ترتبط مع عمق البحر بقانون التربيع العكسي . وفي الواقع فإن هذه العلاقة البسيطة ليست حقيقية نتيجة لتفاعل عدة عوامل لكل منها تأثير على تحليل العمق . وتتضمن هذه العوامل : ضوضاء جهاز الإستشعار، تداخلات الغلاف الجوي ، تأثير النباتات البحرية ، التغيرات في ظروف سطح البحر ، إمتصاص الماء للضوء وإنعكاسيته من قاع البحر.

وقد إستهدف هذا البحث استخراج معلومات دقيقة عن عمق المياه من بيانات الماسح النوعي للقمر الصناعي «لاندسات» التي تتأثر بالعوامل المذكورة مما يمثل بعض القيود التي تحد من دقتها . ويتضمن المنهاج الذي يتم إتباعه في هذا البحث إجراء تصحيح لمصادر الخطأ في بيانات الماسح النوعي للقمر الصناعي «لاندسات» ومحاولة التمييز بين المناطق ذات الأعماق المختلفة بناء على العلاقة مع شدة الضوء . ولتوضيح هذا المنهاج فقد استخدمت عدة طرق للمعالجة الرقمية لبيانات الماسح النوعي للقمر الصناعي بهدف أعداد خريطة لأعماق المياه الضحلة بالخليج العربي شمالي شبه جزيرة قطر . وقد تم تدعيم ذلك بإستخدام معلومات أرضية وبحرية من مصادر متعددة ، تضمنت بيانات المسح البحري بالصدى الصوتي ، خرائط الإدميرالية البريطانية ، الخرائط الطوغرافية للمناطق الساحلية ، وتقارير الأرصاد الجوية ، بيانات المد والجزر ، وغيرها من البيانات المفيدة.

وقد أوضحت هذه الدراسة أن إجراء تصحيحات خاصة بالظروف الجوية والنباتات يمكنها تحسين الإستفادة من بيانات الماسح النوعي للقمر الصناعي «لاندسات» في تحليل أعماق المياه ، كما أن معالجة البيانات المسجلة في المجالين الطيفيين ١ ، ٢ والنسبة بينهما تكون مفيدة لتحليل عمق المياه خاصة في البيئة البحرية الضحلة .

Key words : *Bathymety, digital processing, Landsat-TM, marine enviroment, Qatar.*

ABSTRACT :

The intensity of the light received by Landsat satellite sensors is inversely proportional to the path length though the sea water column, Since the light passes down to the sea floor and back again, the intensity should be related to the depth by an inverse square law. In practice, this simple relation is unlikely to be true due to the effect of several factors, each of which may distort the bathymetric analysis. Among these factors : sensor noise, atmospheric interference; vegetation effect; variations in sea-surface conditions; water absorbency and seabed reflectivity. This work aims at extracting accurate depth information from Landsat-TM data, which is confused by these variations causing some limitations. The approach adopted in this work comprises correction of source error within the Landsat-TM data sets, and a trial to distinguish between areas of variable depth against intensity relationship. To demonstrate this approach, various techniques of digital processing of Landsat-TM imagery data have been applied for bathymetric mapping of shallow water area in the Arabian Gulf, to the north of Qatar Peninsula. It has been corroborated with ground truth information form various data sets including echo sounder date; British Admiralty charts; topographic maps of the coastal area; meteorological and tidal state reports; and other ancillary data.

This study shows that atmospheric and vegetation correction could improve the usefulness of Land-sat TM data bethmetric analysis. Also, processing of Landsat TM band 1 and 2 and their ratio technique is found suitable for analysis of water depth particularly in shallow marine environment.

INTRODUCTION

Remote sensing satellite imagery is a valuable source of hydrographic data in poorly surveyed areas. It covers a wide area on one scene, which allows offshore shoals, reefs and Islands at a far distance from the mainland to be accurately positioned. Multispectral imagery data can also be used to provide a clear coastline and bathymetric information down to about 25 meters. The Landasat and SPOT satellites scan the sunlight reflected from the sea surface and the shallow sea bottoms then registering readings on digital tapes. Through computer analysis of the satellite digital data, water depths can be extracted for each pixel (picture element). Landsat-TM and SPOT-HRV visible spectral channels (blue, green and red) are used for extracting depth. Furthermore, infrared spectral bands of the TM and the panchromatic mode of HRV are used for delineating land/water boundaries. The method requires that several points within the scene of interest have known depths and sea bed materials.

Today, we see that most hydrographic offices have become interested in the application of remotely sensed data, space photography, and airborne (laser and lidar) sensors to hydrographic charting. This technique enables them to maintain the bathymetric charts in an accurate, adequate and up-to-data condition. It also enables them to investigate submarine features in unsurveyed shallow water areas such as our study area off northern Qatar Peninsula. In this area some shoals and coral reefs exist in surrounding waters forming a massive shallow zone extending to the northwest direction within the saline, calm and clear waters of the Arabian Gulf. These can be mapped accurately by using the remote sensing satellites imagery data.

In this respect, some studies have been carried out on the oceanography, marine geology and bathymetry around Qatar Peninsula and other nearby areas of the Arabian Gulf based on the interpretation of photographic prints of various spectral bands of Landsat-MSS and TM (1, 2, 3, 4). Furthermore, digital processing of Landsat-TM data was applied by ERSAC (5) for mapping sea-bed type and water depth around Bahrain, Arabian Gulf. During 1991/1992, a scientific research project was conducted jointly by the Scientific and Applied Research Center (SARC) of the University of Qatar and the Environmental Remote Sensing Center (ERSUN) of the National Remote Sensing Center (NRSC) Ltd., England (6). That research project investigated the use of Landsat-TM data to obtain accurate bathymetric maps and sea-floor DTM, for the offshore area to the north and the west of Qatar Peninsula, Accordingly, a series of seven detailed bathymetric contour maps at scale 1:50,000 and one compiled map at scale 1:100,000 have been produced covering the coast of Qatar Peninsula north of latitude 25° 12' N. The present paper comprises a part of the research project, confined to the northern most part of the area delimited by Latitudes 26° 03' 25" - 26° 30' 30" N and Longitudes 50° 48' 57" - 51° 19' 01" E.

REGIONAL OCEANOGRAPHIC CONDITIONS

The Arabian Gulf is considered to be a small, shallow epicontinental, and nearly landlocked sea. It is surrounded by eight countries, i. e. Iran, iraq, Kuwait, Saudi Arabia, Bahrain, Qatar, U.A.E. and Oman (Fig. 1). The Gulf occupies an area of some 226,000 Km^2, between latitudes 24°-30° N and longitudes 49°-56° E. It extends for about 1000 km in a NW-SE direction, having a maximum width of 300 km in its mid southern part and its narrowest in the straight of Hormuz. The average depth of the gulf is 35m, with the deepest water off the Iranian shore and the shallowest water off the Arabian shore (7, 8).

Being located in an arid region, in which average temperature in the summer is about 35°C and in the winter is around 15°C, the rate of evaporation is very high and the annual rainfall is very low. The river discharges from Shatt Al-Arab, At the northwestern end the Gulf are very small and do not compensate the losses by evaporation. The only compensation for the water lost by high rates of evaporation comes form the net inflow from the Indian Ocean through the narrow strait of Hormuz. This causes a system of counter-clockwise surface currents parallel to the Iranian side. Subsurface currents occur in the Arabian side as the dense water sinks and then flows out through the Strait of Hormuz under the less dense incoming water (9,10,11).

The high rate of evaporation, the low rate of rainfall, the low river discharge, and the slight exchange of water with the Indian Ocean mad the Gulf water very salty. Salinity of the Arabian Gulf is about 4% in average, reaching 7% in some shallow coastal areas that are exemplified by restricted bays and lagoons (11).

The Qatari territorial water are defined as that the body of water which is within the boundaries determined by the State of Qatar for the exclusive use of natural resources including oil and Gas. This total area of territorial water is approximately 35,000 km^2, which represents about 15% of the total area of the Arabian Gulf, Within this area, the surface water temperature may vary from a low mean of 16°C in January and February to a high mean of about 34°C in August. In the deeper area close to the Qatari boundary to the NNE, the low water temperatures vary between 18°C and 22°C. In the lagoons, the temperature may vary between 15°C in the winter and 40°C in the summer. The salinity of the water generally varies 3.9 % and 4.1% at the surface and tends to be 0.1-0.2% higher at the bottom (12).

CHARACTERISTICS OF THE LANDSAT-5 TM SENSOR

Landsat-5 satellite was launched on March 1, 1984 into a sun-synchronus near-polar orbit at an altitude of 705 Km, with a repeat cycle of 16 days and equatorial crossing time at 9:45 a.m. Local sun time. The satellite has a 233-orbit cycle with a swath overlap that varies form 7% at the Equator to nearly 84% at 81° north or south latitude. The satellite carried both the Multispectaral Scanning System (MSS) and the Thematic Mapper (TM) sensors; however the routine collection of MSS data was terminated in late 1992 (13). At present, basic sensor operating on Landsat-5 is the TM whose main characteristics are summarized in Table (1).

The Thematic Mapper (TM) is a highly advanced multispectral scanning system, incorporating a number of spectral, radiometric and geometric design improvements relative to the MSS. The MSS and the TM sensors primarily detect reflected radiation from the Earth in the visible and IR wavelengths, but the TM sensor has seven spectral bands, providing more radiometric information than the MSS sensor with its four spectral bands. The wavelength range for the TM sensor is from the visible through the mid-IR, into the thermal-IR portion of the electromagnetic spectrum. Sixteen detectors for the visible and mid-IR wavelength bands provide 16 scan lines on each active scan. Four detectors for the thermal-IR band provide four scan. The TM sensor has spatial resolutions of 120m for the thermal-IR band, and 30 m for the other six-radiometric bands. Radiometrically, TM performs its on bound analogue-to-digital signal conversions over a quantization range of 256 digital number (8 bits).

The TM band 4 in the reflected near-IR (0.76-0.90 µm) is particularly useful for differentiating between land water where it gives high contrasts, because there is virtually no radiance reflected from water at this wavelength. TM 1 band of blue/green light (0.45 - 0.52 µm) has been designated for water body penetration, coastal water studies and bathymetric mapping, while TM band of green light (0.52 - 0.60 µm) is designed to measure turbidity of water.

Table (1), Thematic Mapper - waveband applications

Band Number	Band Name	Band width (µm)	Band Application
1	Blue/green	0.45 - 0.52	Design for water body penetration-coastal water mapping. Strong vegetation absorbance differentiates soil and rock from vegetation.
2	Green	0.52 - 0.60	Designed to measure green reflectance of vegetation. Also turbidity of water.
3	Red	0.63 - 0.69	Absorbs reflections from vegetation and detects ferric ions, useful in lateritic terrains in determining the underlying geology.
4	Near Infrared	0.76 - 0.90	Gives high land/water contrasts and very strong vegetation reflectance.
5	Near middle infrared	1.55 - 1.75	Differentiates clouds from snow and is very moisture sensitive
6	Thermal infrared	10.4 - 12.5	Of use in stress analysis, soil moisture discrimination, and surface temperature studies.
7	Middle infrared	2.08 - 2.35	Discriminates rock types and detects hydrothermally altered zones around some mineral deposits.

MATERIAL AND METHODOLOGY

This work is mainly based on digital image processing, analysis and interpretation of Landsat-5 TM scene, Path 163/Row 42, acquired on 6th June 1990. This scene covers almost the northern half of Qatar Peninsula and the surrounding offshore shallow water of the Arabian Gulf, between Latitudes 25° 02' - 26° 57' N and Longitudes 49° 46' - 52° 02' E. However, the study is restricted to the northern part of the scene, delimited by Latitudes 26° 03' 25" - 26° 30' 30" N and Longitudes 50° 48' 57" - 51° 19' 01" E. covering an area of some 2500 km^2 most of it offshore the northern tip of the Qatar Peninsula (Fig 2). Accordingly, digital data of subscene covering this area have been extracted from the original Landsat-TM scene for the present study.

Various image-processing techniques have been applied on the Landsat-TM subscene, using ERDAS system. Details about software and processing operations on this system are given by ERDAS, Inc. (14) and Fromberg *et al* (6). Since the investigated subscene covers the land and sea areas and in order to obtain an optimal stretch, each were stretched separately before land and sea areas were combined. The used ERDAS software (version 7.5) includes a set of programs that allows :

- interactive piecemeal linear stretches to be designed for each image band.
- edge enhancement of land areas by filtering, then combination of the separately enhanced land and sea portions of the image,
- generation of DTM using appropriate depth inversion algorithm and conversion to GIS file,
- Contouring the DTM data and producing a bathymetric image map.

For the purpose of the present study several processing techniques, have been applied to investigate the capabilities and limitations of Landsat-TM data for bathymetric analysis. The main performed techniques include the following :

1. Noise reduction including line fixing, destriping, smoke correction and vegetation correction.
2. Rationing of spectral bands, using a simple ratio and a normalized ratio of TM bands 1 and 2.
3. Geometric correction using available ground control points.
4. Depth inversion and bathymetric analysis.

DISCUSSION

Digital data from Landsat-TM has been processed by some special techniques and algorithms to obtain good light penetration of water to enable recognition of sea-bottom topography and hence water depth. The position of the depth contours shown on the hydrographic charts has been reproduced from the processed satellite data with a good correlation (Fig. 3). However, some local variations are identified mostly with under-estimated depth values.

Despite this capability of using Landsat-TM data for bathymetric analysis, there are still some obstacles to produce accurate and reliable measurements of water depth in marin environment. The main constraints for operational bathymetric mapping from Landsat-TM data can be summarized in the following :

1. Sensor accuracy which cannot, so far, match the accuracy and reliability of «in-situ» measurements form ship-based surveys.
2. Cloud cover inability of the visible light recorded by the Landsat-TM sensor to penetrate clouds.
3. Limited depth of light penetration in seawater, where areas of water deeper than 20 meters cannot be reliably mapped. Also, the distribution pattern and dense growth of algae and coral reefs decrease the euphotic zone, i.e. the zone with light sufficient for photosynthesis. This is in addition to the effect of suspended sedimetns.
4. Changes in the nature of substrate, where e.g. areas of sandy sediments appear to have a greater reflectance than those with a rocky substrate.
5. The availability of sea-truth informatin or accurate survey maps and timely meteorological data for the study area to select training sets necessary for digital processing and calibration of satellite data of the unsurveyed area.
6. Pattern of marine sedimentation, rate of tidal movements, distribution of sandbanks and shoals; type and pattern of marine pollutants particularly from oil spills.

CONCLUSION

This study revealed that Landsat-TM imagery data could provide useful information on sea depth and differences in bottom topography within the shallow water of the Arabian Gulf around Qatar Peninsula. It has been found that digital processing of Landsat-TM data band 1 and band 2 and their ratio is a suitable technique for bathymetric analysis of shallow marine environment. The technique developed in this study includes atmospheric and vegetation corrections that have improved the usefulness of Landsat-TM data for bathymetric mapping and overcome some of its limitations. The produced map has bathymetric contour interval of one meter to a depth of 13 m with an accuracy of $\pm$ 1.0 m (Fig.3).

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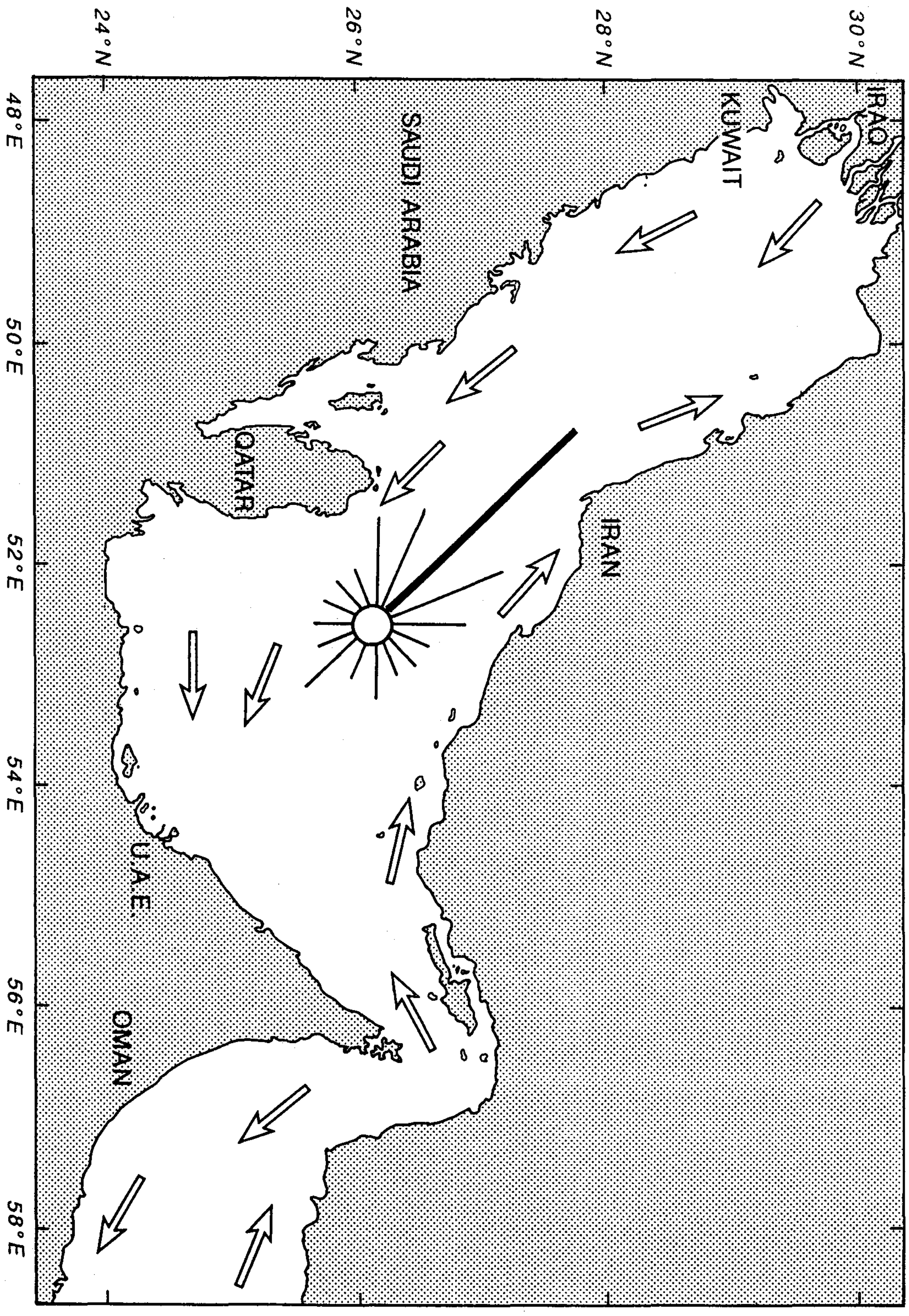
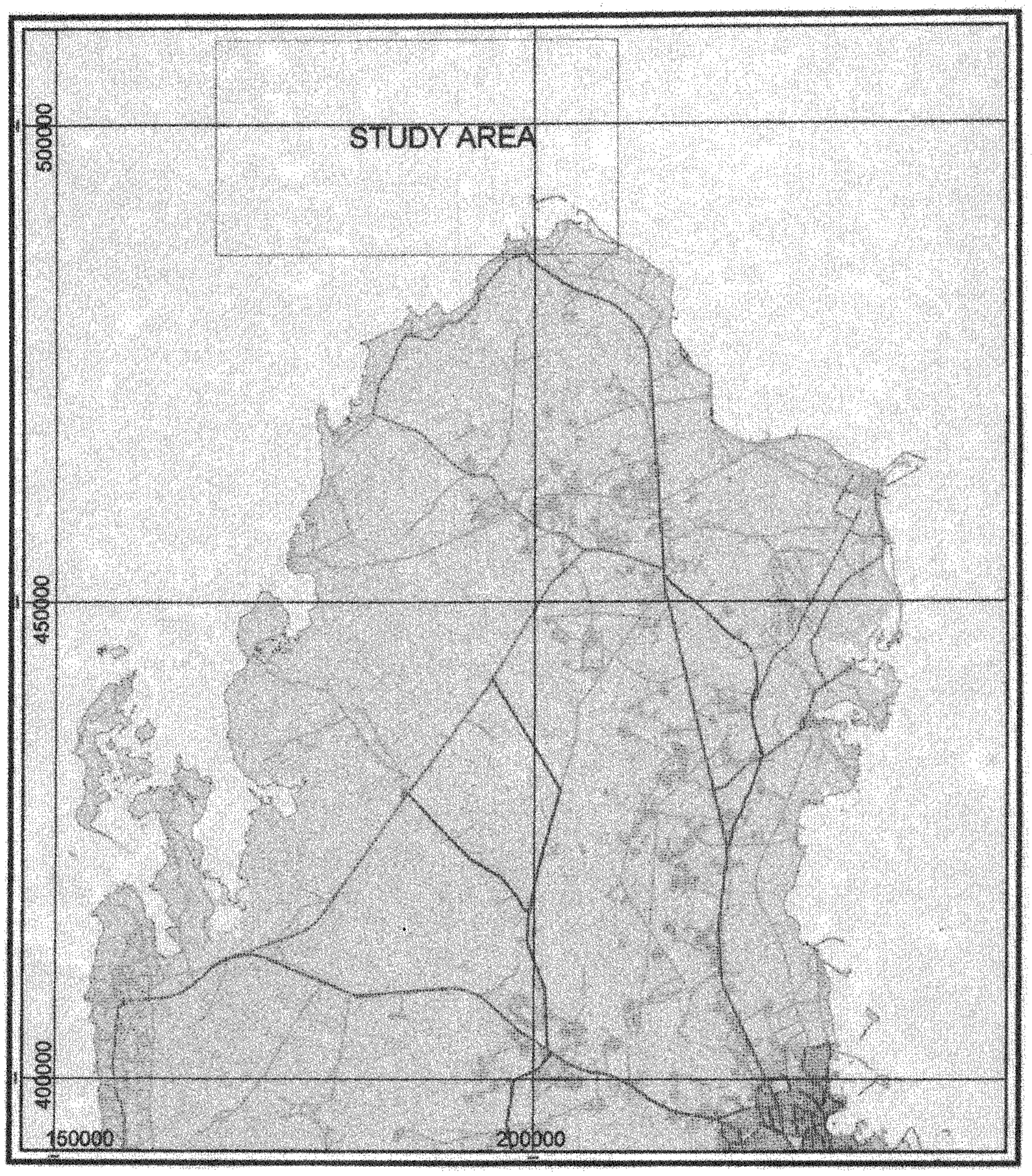
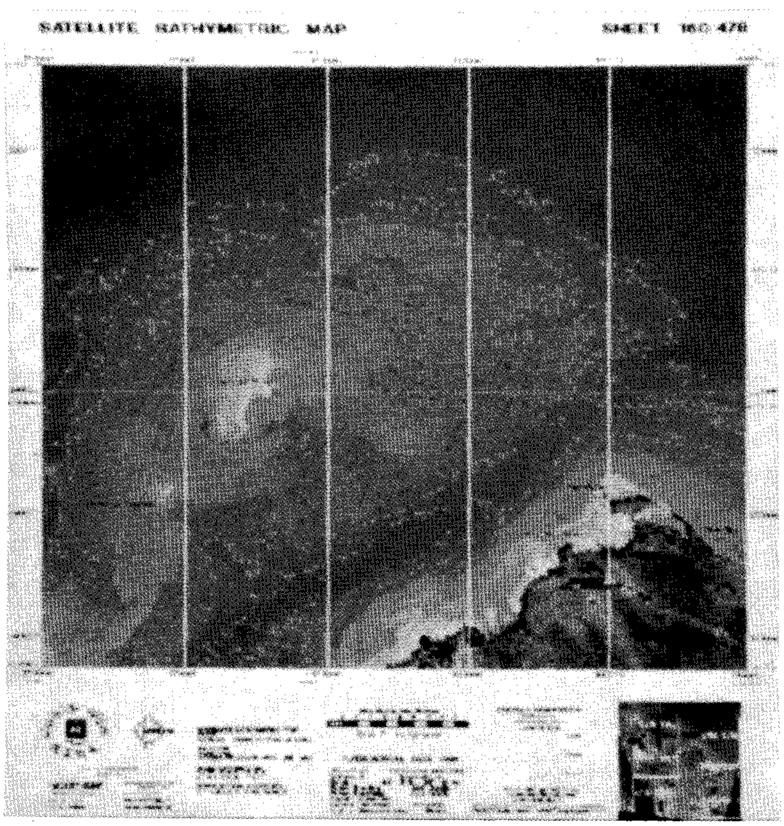

24°N
26°N
28°N
30°N
48°E
50°E
52°E
54°E
56°E
58°E
IRAQ
KUWAIT
SAUDI ARABIA
QATAR
IRAN
U.A.E.
OMAN

(**Fig. 1**)



(Fig. 2)



(Fig. 3)