# Quantitative Assessments of Land Reclamation along the East Coast of Saudi Arabia

BY

Tawfiq A. Al-Rowaished

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## DEANSHIP OF GRADUATE STUDIES

This thesis, written by Tawfiq Abdullah Naser Al-Rowaished under the direction of his thesis advisor and approved by his thesis committee, has been presented and accepted by the Dean of Graduate Studies in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE IN **ENVIRONMENTAL SCIENCES**.

Thesis Committee

Dr.Assad A. Al-Thukair
(Chairman)

Dr. Baqer AL-Ramadan
(Member)

Dr. Nasser Al-Homaid
(Member)

Dr.Abdulaziz M. Al-Shaibani
(Department Chairman)

Dr.Salam A.Zummo
(Dean of Graduate Studies)

3/1/12

Date

# DEDICATION

**This Thesis is gratefully**

**Dedicated**

**To**

**My Family**

## ACKNOWLEDGMENTS

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# THESIS ABSTRACT

**Name:** **Tawfiq A. Al-Rowaished**

**Title:** **Quantitative Assessments of Land Reclamation along the East Coast of Saudi Arabia**

**Major Field:** **Environmental Sciences**

**Date of Degree:** **December 2011**

This study identifies the land reclamation activities in eastern cost of Saudi Arabia and quantifies the reclaimed lands within Tarut Bay from 1970 until 2007. The total land that has been reclaimed within Tarut Bay area since 1973 up to November 2007 were found to be 84.42 square kilometers ($Km^2$) most of which were utilized for residential purposes. The research study found out that most of land reclamation activities were carried before November, 1995. The amount of reclaimed land due to reclamation activities since 1973 until 1995 was found to be around 83.68 square kilometers ($Km^2$) whereas the reclamation activities after November 1995 were found very little and the total reclaimed area up to 2007 were only 0.74 square kilometers ($Km^2$). The study also show some environmental consequences due to reclamation activities within Tarut bay area. The superimpose of environmental biotype map of Tarut Bay marine life with 1995 and 2007 reclaimed area within that bay, show a clear and destructive impact on mangrove habitats which Tarut Bay were very rich and famous on it.

**ملخص الرسـالــة**

هذه الدراسة  توصلت الى تعريف وحساب كميات الأراضي المستـصلحه من أراضـي الشواطئ ، من خـلال عـمليات دفـن الشـواطئ وضم أراضيها الى اليابسة و خاصـة في خليج تاروت من 1970 – 2007. توصلت الدراسة ان مجموع الأراضـي المستـصلحه من خـليج تاروت من الفترة 1973 إلى 2007 بلغت ما مجموعه 84.42 كيلومترمربع والتي استخدمت لغرض الاسكان. كما توصلت هذه الدراسة بأن أغلب عمليات الدفن و الإستصلاح حدثت قبل نوفمبر 1995. كذلك أوضحت الدراسة أن مجموع الأراضـي الأكـبر أستصلحت من تاريخ 1973 إلى 1995 قد بلغت 83.68 كيلومترمربع. أما مساحات الأراضي التي استصلحت ما بعد 1995 إلى 2007 بلغـت ما مجموعة 0.74 كيلومـتـرمربع وهذا في خليج تاروت وحده. كما أن الرسالة توصلت الى أن عمليات الدفن ساهمت في تلاشي اشجار المـانجـروف وذلك بعد مطابقتها مع خريطة الأحياء البحرية في خليج تـاروت.

# CHAPTER 1

# INTRODUCTION

Coastal waters support fish populations that constitute a significant source of protein, sustain ecosystem stability through conservation of biodiversity, mitigate climate change through carbon sequestration, act as sinks for by product of industrial or agricultural production, and provide recreational and aesthetic benefits. Marine and coastal natural resources are, for the most part, renewable. If properly managed, they should provide continuing returns into the future without diminishing their productivity. However, increasing human activities in coastal areas exert growing pressure on the marine and coastal ecosystems. In order to ease the problem of land shortage, reclaiming land from the sea has become a common approach in many parts of the world. In fact, large-scale land reclamation has caused significant damage to coastal ecosystems and the services they provide. Land reclamation occupies coastal space, permanently change the intrinsic natural quality (e.g., topography, physiognomy and shoreline) of a coastal ecosystem, and alter the hydrodynamic effect of sediment transport or inshore current systems, as well as endanger the animals and plants (e.g., benthic organisms and mangroves) in and near the reclamation area , all of which will directly or indirectly damage the provisioning, regulating, cultural and supporting services generated by the coastal ecosystem. For example, reclamation may change seaside and sandy beaches which provide the aesthetic and recreational service; it would reduce tide-absorbing capacity of a bay, causing damage to waste treatment service; it may destroy coastal plants and phytoplankton which play an important role in gas regulation service through photosynthesis; it may also destroy mangroves(3) and coral reefs which provide erosion control service as natural coastal defense against storm surges and biodiversity maintenance service as important habitats for fish and wildlife. Ecosystems maintain their functional integrity through a natural balance of materials and energy flowing through, cycling within, and leaving them. This equilibrium is supported by natural, physical, chemical and biological processes. Land reclamation may disturb the equilibrium or destroy coastal ecosystems

Reclamation can occur both on land and on sea. Land may either be reclaimed for reasons of raising the level of existing physical ground or for fill purposes of land being mined for resource extractions. The most common form of reclamation practices is reclamation occurring in the sea or most simply put, reclamation is the forming of land by filling the sea. The main object of reclaiming land from the gulf sea in Tarut bay area is to increase the area of ground available for establishing various physical purposes. These may range from residential and cultivation purposes to major development projects such as tourism, individual/commercial business ventures and other infrastructural improvement.

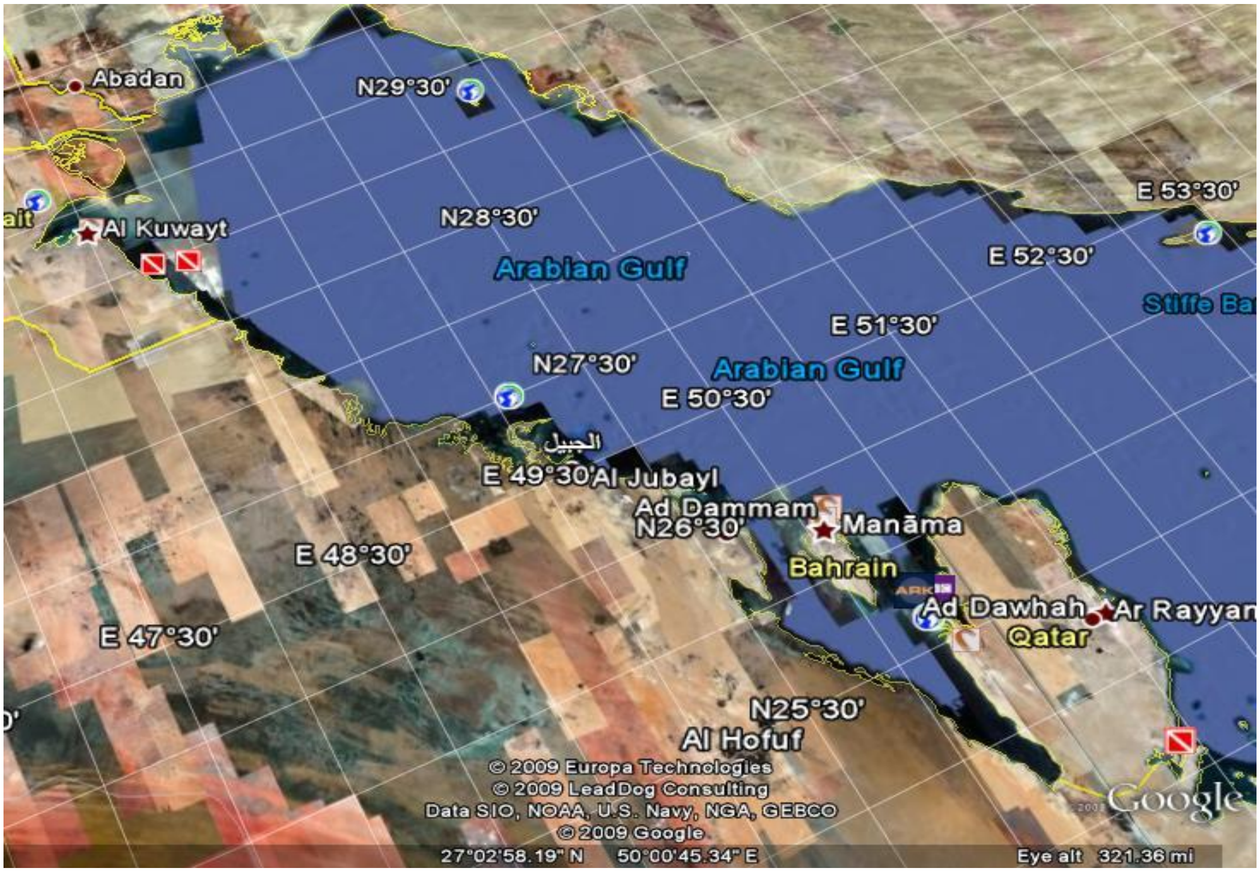

Figure (1): The Eastern Province Shore Line.

Reclamation can incur both positive and negative impacts on the coastal environment. On the one hand it helps add resilience to vulnerability of the sea-and-coast's physical coexistence while on the other it can incur heavy losses to ecosystems of the immediate coastal environment. Placing fill in a reclamation area may affect the water quality of the adjacent sea as well as threatening the thriving existence of fish stocks and habitats found in coastal seas and connecting lagoons.

Throughout the history, civilization was born on the banks of large rivers, such as the Nile, the Euphrates, and Tigris. Protection against flooding and creating deep access to maritime sea routes were the basic requirement for creating nation prosperity. In the course of many centuries land reclamation have emerged as means for creating water-bound prosperity and economic development. More than 60 percent of the world's population lives less than 100 kilometers from open water (38). Of the world's nineteen mega cities with over ten million inhabitants, thirteen of them are built in coastal zones. Water is both a threat and an opportunity to mankind.

Figure (2): Mangrove impact due to reclamation activity in Tarut Bay.

Land reclamation and its effects on ecological systems have received worldwide attention since couple of decades. Land reclamation is either of two different practices. One involves creating new land from sea or riverbeds the other refers to restoring an area to a more natural state and rehabilitate it after pollution, salination or desertification. In this paper we will discuss the history and quantify the reclaimed land from Arabian Gulf particularly in east coast of Saudi Arabia (figure 1), since 1970 using remote sensing of landsat images technology. An addition, this study will discuss the environment impact of land reclamation on ecology (figure 2) and the different usages of the reclaimed land since nineteen seventy.

### 1.1 Land reclamation worldwide

Generally, creating new land practices serve the communities and countries for different purposes. The three major reclamation activities worldwide are habitation, agriculture and beach restoration. Big cities reclaim new land mostly for habitation notable examples in United State include parts of New Orleans and Washington D. C which is partially built on land that was once a swamp. In Europe, Helsinki major part of its city center is built on reclaimed land. In Far East, Japan, the southern Chinese cities, the city-state of Singapore, Shenzhen and Hong Kong where all land in short supply are famous for their efforts on land reclamation (38). One of the earliest and famous projects was the Praya Reclamation Scheme which added 50 to 60 acres (240,000 m2) of land in 1890 during the second phase of construction. It was one of the most ambitious projects ever taken during the Colonial Hong Kong era (4). Marine plankton and benthos have been affected by reclamation projects in Tianjin Harbor Industrial Zone. The results showed that the Shannon-Weaver diversity index of phytoplankton and zooplankton decreased from 3.01 to 1.71 and 1.7 to 0.58, respectively. In addition, the diversity index of Shannon-Weaver of benthos decreased to zero from 1.28.

The results showed that reclamation projects would change the living environment of marine organism, decrease the diversity of biology and change the structure of community (2).

Figure (3): Different Land reclamation site in Hong Kong.

### 1.2 Land Reclamation in Arabian Gulf

In Arabian Gulf, lots of land reclamation activities were developed after the commercial discovery of crude oil. The most famous reclamation activities are the development project of the Palm islands, the world, hotel of Burj al-Arab, and Dubai water front in the United Arab

Emirates are all examples of land reclamation and artificial islands creation. During the past decades, a number of sites along the coast of Bahrain have been either reclaimed or dredged. A total area of approximately 34 $km^2$ was gained through these operations. These operations have drastic effects on the coastal marine ecosystems and environments. They have induced siltation, increased turbidity of the sea water and of the salinity of the island's ground waters. They have further degraded the biosystem, with many coral colonies, mangroves and sea grass beds destroyed (5).

Figure (4): Dubai artificial islands

### 1.3 Land reclamation in Saudi Arabia

In Saudi Arabia and particularly Eastern Province, for the last three decades there has been major and rapid development in infrastructure and life style following the oil discovery in early 1930's. Existing cities have expanded and new ones were well planned to cope with such rapid growth in population. Major construction of oil refineries, industrial cities, and acceleration in building of infrastructure in the Eastern Province did occur between 1960 to 1990 resulted in vast land reclamation activities. This type of land reclamation and island creation had destructive effect on healthy marine life (figure 6) and its ecology especially with rich ecosystem of Arabian Gulf. These reclamation activities added considerable amounts of flat area for habitation but in the same time impact environment and destroy marine habitat and its ecology especially the mangrove (3). When the natural habitat disturbed it will no more support the species originally present and the biodiversity in those reclaimed site will be reduced and habitats such as mangrove (figure 2) will be missed up and bury under such reclamation, urbanization, and dredging activities.

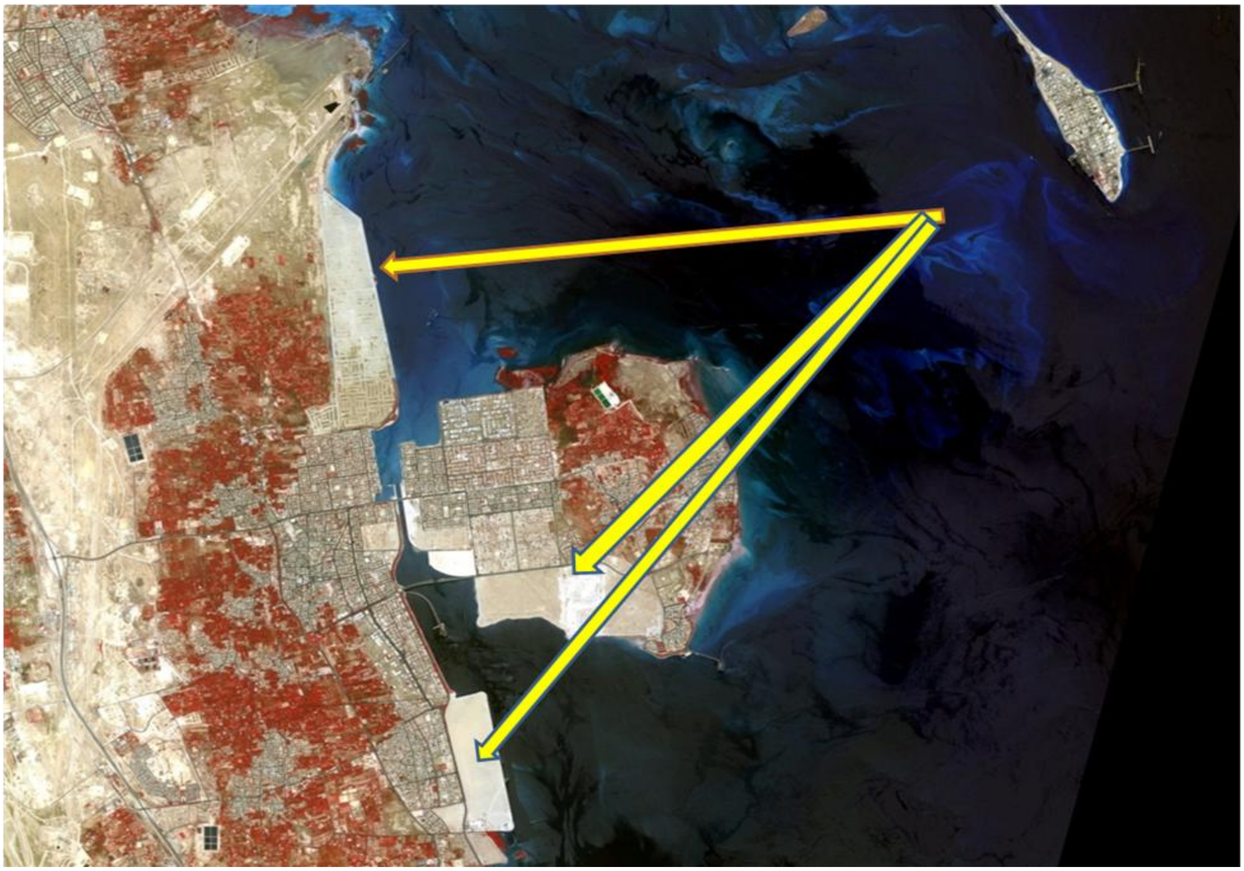
Figure (5): Land reclamation sites in Tarut Bay.

In this study, I quantify the reclaimed land along the shoreline of eastern province of Saudi Arabia. I utilized remote sensing images technology together with geographical information system (ArcView GIS) application software’s to quantify the reclaimed land. In addition, the study also classified the different usage of the reclaimed land and its impact on environment.


Figure (6): Healthy mangrove habitat in Eastern province of Tarut Bay.

In order to quantify and estimate the land reclamation activities along the coastal line of Eastern province of Saudi Arabia and be able to determine its environmental impact on marine habitat along the Arabia Gulf coastal line, I utilized remote sensing technologies to obtained different timing of satellite images. In this study and based on images availabilities, I utilized different timing of spot, Thematic Mapper TM, and Landsat Multi Spectral Senses MSS images for the coastal line to detect and quantify the reclaimed land from Arabia Gulf since 1973 till 2007. I acquired the TM and Spot satellite images of 1995 and 2007 from King Abdulaziz City for Science and Technologies (KACST) and Landsat MSS of 1973 images from King Fahad University of Petroleum and Minerals (KFUPM).


Figure (7): MSS of Tarut bay in 1973, Eastern Province of Saudi Arabia.

Since the 1973 Landsat MSS images are not geo-corrected, I utilized 1995 TM images to correct them using ER Mapper which is a powerful tool and easy-to-use image processing and integrated mapping software application product. In this study I utilized the ER Mapper applications software to enhance couples of satellites images and use them to geo-correct the MSS 1973 images with TM 1995 images baths and rows coordinates to make sure that there isn't any overlapping in images.

In order to have good comparison of different dates of images, some of 1973 images were geo-corrected and co-registered to WGS84/NUTM39 in ER mapper then all images of different dates (1973, 1995, and 2007) were uploaded in GIS software in which we created different timing of costal line mosaic images as shown in (figures 10,11 & 12).

After a through revision for land reclamation activities along the Eastern province cost line using different timing mosaic images, we found out that the most reclamation activities took place in Tarut bay (figure 8). Since the only environmental biotype map available of marine habitat in hand for Tarut bay, we limit our reclamation land quantification assessments to Tarut Bay area only.


Figure (8): Spot of Tarut bay in 2007, Eastern Province of Saudi Arabia

# CHAPTER 2

# Literature Review

There were many research studies that used remote senescing technology to calculate land, water, and vegetation cover changes that subsequently impact the environments and ecosystem.

## 2.1 Land reclamation in Hong Kong

One of the earliest and famous projects was the Praya Reclamation Scheme which added 50 to 60 acres (240,000 m$^2$) of land in 1890 during the second phase of construction. It was one of the most ambitious projects ever taken during the Colonial Hong Kong era (4).

## 2.2 Detecting Mangrove Changes Using Landsat Imagery

This study highlighted that land reclamation activities play big role on destroying marine habitat such as mangrove as show in (figure 2). The results of this study confirm the dramatic decrease in mangrove habitat within the Tarut Bay study area. The study has demonstrated the feasibility of using Remote Sensing techniques, especially the Spectral Angle Mapper to track environmental phenomena. The decrease in mangrove population during the 1990s was found to be around 500 acres or roughly 35%. The results of the study indicate that mangrove habitat in the study area has decreased by about 35% between 1990 and 1999.

### 2.3 Coastline changes between Kilyos and Kamaburun shoreline

This study detect the shoreline changes by the amount of area filled with excavated material and conclude that coastline is being altered dramatically by indiscriminate and uncontrolled open-surface mining. The study calculates that 160 +/- 10% hectares of coastal water have been filled up with excavated material and 590 +/- 10% hectares of forest have been destroyed in Istanbul.

### 2.4 Environmental changes and infrastructure development

This study used Landsat TM data to examine the environmental impact of east Port Said harbor. The study detect declined in wetland area from 103 km2 in 1984-1991 and 1991-2003.

### 2.5 A methodology of characterizing status and trend of land changes in the oasis of Sangong River in Xinjiang, Northwest China

The study monitor the expansion and contraction among various land types and for the entire oasis of Sangong river in Xinjiang were analyzed for the periods of 1978-1987, 1978-1998 and 1987-1998. It concludes that changes in land use were closely related to a strong economic growth after the land-reform campaign and adoption of market economy in China in the late 1980s to early 1990s.

## 2.6 Evolution of the Sungei Buloh-Kranji mangrove coast, Singapore

The study shows that a time series of photographs covering the period from 1946 to 2001 has revealed major changes in the distribution of mangroves in the area resulting from development-induced changes in the local hydrodynamic regime and clearance for aquaculture. Mangroves covered 117.3 ha in the study area in 1946 and were actively advancing over the coastal mudflats until 1980. Despite the addition of 6.24 ha from mangrove colonization, the total area covered by mangroves was reduced by ~50% by 1980 due to clearance for aquaculture.

# CHAPTER 3

## Research Objectives

**i.** To quantify the reclaimed land within Tarut Bay from Arabian Gulf toward the shore line of Eastern coast of Saudi Arabia from 1973 until 2007.

**ii.** To identify and classify the land uses of the reclaimed land, and effected marine habitats in the studied area.

## Problem Definition

Arabian Gulf located in the southwest Asian region and it is an extension of Indian Ocean. This inland sea of some 251,000 km² is connected to the Gulf of Oman in the east by Strait of Hormuz and its western end is marked by the major river delta of the Shatt al-Arab, which carries the waters of the Euphrates and the Tigris. Its length is 989 kilometers with Iran occupying most of the northern coast and Saudi Arabia most of the southern coast. The gulf is about 56 kilometers wide at its narrowest, in the strait of Hormuz. It is rich with good fishing grounds, extensive coral reefs, and abundant of pearl oysters but its ecology has come under pressure especially after the oil discovery in the region and the boom of industrialization and cities expansion.

Shoreline of the Arabian Gulf overall very shallow and make it easy and less expensive to reclaim land from it. In the last decades, Arabian Gulf was effected by major and numbers of urban development projects which led to land expansion activities ranging from beach replenishment up to island creation. The most recent and modernize land reclamation in the gulf are the creation of three artificial islands palm, the world, and Dubai waterfront. The islands located off the coast of the United Arab Emirates and will add 520 kilometers of beaches to the city of Dubai.

Since the oil discovery in early 1930's, Saudi Arabia had undergone major and rapid development in infrastructure and life style. Existing small cities were expanded and new ones had well planned to cope with such growth in population. Major construction of oil refineries, industrial cities, and acceleration in building of infrastructure in the Eastern province did occur between 1960 to 1990 resulted in land expansions especially the Eastern coast shoreline cities from the most developed one Dammam up to Khafji. These types of land reclamation and island creation have destructive effect on marine life and its ecology especially with rich ecosystem such as the Arabian Gulf. Since 1990 little research studies discuss the ongoing land reclamation activities at the Eastern coast of Saudi Arabia. This study will discuss the land reclamation activities that took place since 1973 onward to 2007 and provide the current status and total quantity of land reclaimed from Arabian Gulf. It will also identify the environmental impact on marine habitats due to such activities.

# CHAPTER 4

# DATA HANDLING

To execute our study of land reclamation activities along the eastern coast of Saudi Arabia, we gathered east cost satellite images for different timing (1973, 1995, and 2007).

## 4.1 Data Acquisition

Different datasets were obtained for the purpose of this study. Twenty nine main imagery datasets were obtained from the King Abdulaziz City of Science and Technology (KAUST). Those were mainly Landsat scenes obtained at different times for the study area. Table 1 shows the different datasets obtained for the purpose of this study and their characteristics. In addition to these data, imagery of Tarut bay from KAUST satellite group was provided ready geo-corrected by KFUPM RI remote sensing unit covering the study area.

**Table 1**: Summary of 1973 WRS Image Data

| | Landsat MSS | Landsat MSS | Landsat MSS | Landsat MSS | Landsat MSS | Landsat MSS |
|---|---|---|---|---|---|---|
| **Reference WRS** | 175-42 | 175-43 | 176-41 | 176-42 | 177-40 | 177-41 |
| **Acquisition Date** | 04/10/73 | 04/10/73 | 04/10/73 | 04/10/73 | 04/10/73 | 04/10/73 |
| **Bands** | 3 | 3 | 3 | 3 | 3 | 3 |
| **Resolution (m)** | 58 | 58 | 58 | 58 | 58 | 58 |
| **Datum** | WGS84 | WGS84 | WGS84 | WGS84 | WGS84 | WGS84 |
| **Projection** | NUTM39 | NUTM39 | NUTM39 | NUTM39 | NUTM39 | NUTM39 |
| **Source** | KFUPM | KFUPM | KFUPM | KFUPM | KFUPM | KFUPM |

## 4.2 Landsat MSS Scenes

Six scenes dating October 04th, 1973 were obtained from KFUPM Table 1. Although the resolutions of these datasets are not good enough, and not compatible with the later datasets, it has provided an insight to the situation of shoreline during that period.

**Table 2**: Summary of 1995 WRS Image Data

| | **Landsat TM** | **Landsat TM** | **Landsat TM** | **Landsat TM** | **Landsat TM** |
|---|---|---|---|---|---|
| **Reference WRS** | 163-42 | 163-43 | 164-41 | 164-42 | 165-40 |
| **Acquisition Date** | 11/11/95 | 11/11/95 | 08/04/95 | 08/04/95 | 21/08/95 |
| **Bands** | 3 | 3 | 3 | 3 | 3 |
| **Resolution (m)** | 30 | 30 | 30 | 30 | 30 |
| **Datum** | WGS84 | WGS84 | WGS84 | WGS84 | WGS84 |
| **Projection** | NUTM39 | NUTM39 | NUTM39 | NUTM39 | NUTM39 |
| **Source** | KACST | KACST | KACST | KACST | KACST |

### 4.3 Landsat TM Scenes

Five Landsat 4 Thematic Mapper scenes numbered 163/42,163/43,164/41,164/42, and 165/40 were obtained from KACST dating November 11th, April 08th, and August 21th 1995. These scenes were provided orthorectified although further local co-registration was required to ensure comparability with other dates. As shown in Table 2, it provides higher resolution than that provided by the MSS scenes obtained for 1973 as mentioned above.

**Table 3**: Summary of 2007 WRS Image Data

| | **Landsat SPOT** | **Landsat SPOT** | **Landsat SPOT** | **Landsat SPOT** | **Landsat SPOT** | **Landsat SPOT** |
|---|---|---|---|---|---|---|
| **Reference WRS** | 147-293<br>153-297<br>151-297 | 148-293<br>153-298<br>152-297 | 149-294<br>153-299<br>152-296 | 149-295<br>154-299<br>152-298 | 150-295<br>154-300<br>151-296 | 151-295<br>155-300<br>155-301 |
| **Acquisition Date** | 2007 | 2007 | 2007 | 2007 | 2007 | 2007 |
| **Bands** | 3 | 3 | 3 | 3 | 3 | 3 |
| **Resolution (m)** | 10 | 10 | 10 | 10 | 10 | 10 |
| **Datum** | WGS84 | WGS84 | WGS84 | WGS84 | WGS84 | WGS84 |
| **Projection** | NUTM39 | NUTM39 | NUTM39 | NUTM39 | NUTM39 | NUTM39 |
| **Source** | KACST | KACST | KACST | KACST | KACST | KACST |

## 4.4 Landsat SPOT Scenes

Eighteen Landsat SPOT scenes as numbered above were obtained from KACST during 2007. These scenes were provided with higher resolution and region of interest was further co-registered to ensure comparability with other and previous dates. As shown in Table 3, it provides with higher resolution than that provided by the MSS or TM scenes obtained for 1973 and 1995 as mentioned above.

**Other Data acquired for the project included:**

Environmental protection biotype map of marine habitat for Tarut Bay obtained from the Center for Environment and Water at KFUPM.

# CHAPTER 5

## Remote sensing

In order to estimate the land reclamation activities along the Tarut bay in Eastern province of Saudi Arabia and be able to determine its environmental impact on marine habitat, this study has utilized remote sensing technologies to obtained different timing of satellite images to quantify the reclaimed land from Arabia gulf toward Tarut bay.

Remote sensing is the small or large-scale acquisition of information of an object by the use of either recording or real-time sensing devices that are wireless by way of satellite. In practice, remote sensing is the stand-off collection through the use of a variety of devices for gathering information on a given object or area.

### 5.1 Passive Sensors

There are two kinds of remote sensing. Passive sensors detect natural radiation that is emitted or reflected by the object or surrounding area being observed. Reflected sunlight is the most common source of radiation measured by passive sensors such as Spot satellite. Examples of passive remote sensors include film photography, infrared, charge-couple devices and radiometers. Active collection, on the other hand, emits energy in order to scan objects and areas whereupon a sensor then detects and measures the radiation that is reflected or backscattered from the target.

## 5.2 Remote sensing applications

Remote sensing makes it possible to collect data on dangerous or inaccessible areas. Remote sensing applications, include monitoring deforestation in areas such as the Amazon Basin, the effects of climate change on glaciers and Arctic and Antarctic regions, depth sounding of coastal, and land reclamation a long coastal area as this research study focus on in which we used one of remote sensing tools such as Spot, TM, and MSS satellites images to detect and quantify the reclaimed land from Arabian gulf since 1973 till 2007.

## 5.3 SPOT Satellite

SPOT (Satellite Pour l'Observation de la Terre), is a high-resolution, optical imaging Earth observation satellite system operating from space. It is run by Spot Image based in Toulouse, France. It was initiated by the CNES (Centre national d'études spatiales — the French space agency) in the 1970s and was developed in association with the SSTC (Belgian scientific, technical and cultural services) and the Swedish National Space board (SNSB). It has been designed to improve the knowledge and management of the Earth by exploring the Earth's resources, detecting and forecasting phenomena involving climatology and oceanography, and monitoring human activities and natural phenomena. The SPOT system includes a series of satellites and ground control resources for satellite control and programming, image production, and distribution. The satellites were launched with the ESA rocket launcher Ariane 2, 3, and

4.The company SPOT Image is marketing the high-resolution images, which SPOT can take from every corner of the Earth.

## 5.4 Thematic Mapper

Thematic Mapper (TM) is one of the Earth observing sensors introduced in the Landsat program. TM was first placed aboard Landsat 4 (decommissioned in 2001), and one is still operational aboard Landsat 5 as of May 2007. Its sensors feature seven bands of image data (three in visible wavelengths, four in infrared) most of which have 30 meter resolution. Thematic Mapper has become a useful tool in the study of albedo and its relationship to global warming and climate change. The TM on the Landsat 5 has proven useful in determining the amount of ice loss on glaciers due to melting.

## 5.5 ER Mapper

In this study and based on images availabilities, we utilized different timing of spot, TM, and Landsat MSS images for the coastal line of Eastern province of Saudi Arabia to detect and quantify the reclaimed land from Arabian Gulf since 1973 till 2007. I acquired the TM and Spot satellite images of 1995 and 2007 from King Abdulaziz City for Science and Technologies (KACST) and Landsat MSS of 1973 images from King Fahad University of Petroleum and Minerals. Since the 1973 Landsat MSS images are not geo-corrected we utilized 1995 TM images to correct them using ER Mapper, which is a powerful tool and easy-to-use image processing and integrated mapping software product. It is used worldwide for resource management, urban planning, mineral/oil exploration, and many other applications.

In this study I utilized the ER Mapper applications software to enhance different satellites images to use them to geo-correct the MSS 1973 images with TM 1995 images baths and rows coordinates. In order to have good comparison of different dates of images, some of 1973 images were geo-corrected and co-registered to WGS84/NUTM39 in ER mapper then all images of different dates (1973, 1995, and 2007) were uploaded in GIS software to draw the boundary of Eastern Province cost line and then quantify the reclaimed land for different period of time.

## 5.6 ARC GIS System

The GIS system, is basically geographic information system that integrates, stores, edits, analyzes, shares, and displays geographic information data.GIS applications are tools that allow users to analyze spatial information, edit data, maps, and present the results of all these operations. New versions of GIS technologies use digital information, for which various digitized data creation methods are used. The most common method of data creation is digitization, where a hard copy map or survey plan is transferred into a digital medium through the use of a computer-aided design program, and geo-referencing capabilities.

The GIS program can also convert existing digital information, which may not yet be in map form, into forms it can recognize and use. For example, digital satellite images generated through remote sensing such as different images of Eastern Province costal line can be analyzed to produce a map-like layer of digital information about sea reclaimed area.

I selected three subsection sets for the area of interest for different timing starting from 1973, 1995 and till 2007. Then those subsection images where registered, geo-coded, and enhanced using the ER Mapper software. Then the different subsection images uploaded as layers in ARC GIS software where the reclaimed area digitized and quantified.

# CHAPTER 6

# METHODOLOGY

### 6.1 Image Processing

In order to achieve the final goal of extracting land reclamation areas in different satellite scenes, I had to manipulate, enhance, and analyze the images at hand. The steps involved in this processing are explained in the sections below.

### 6.2 Mosaicing Different Scenes to Create Single Datasets

In order to be able to deal with study area as a single dataset, different scenes were mosaiced together using histogram matching techniques to conduct color balancing after the initial atmospheric effects correction. The mosaicing operation created three single, atmospherically corrected, color-balanced datasets out of the main costal mosaic Landsat images (figures 9, 10 & 11).

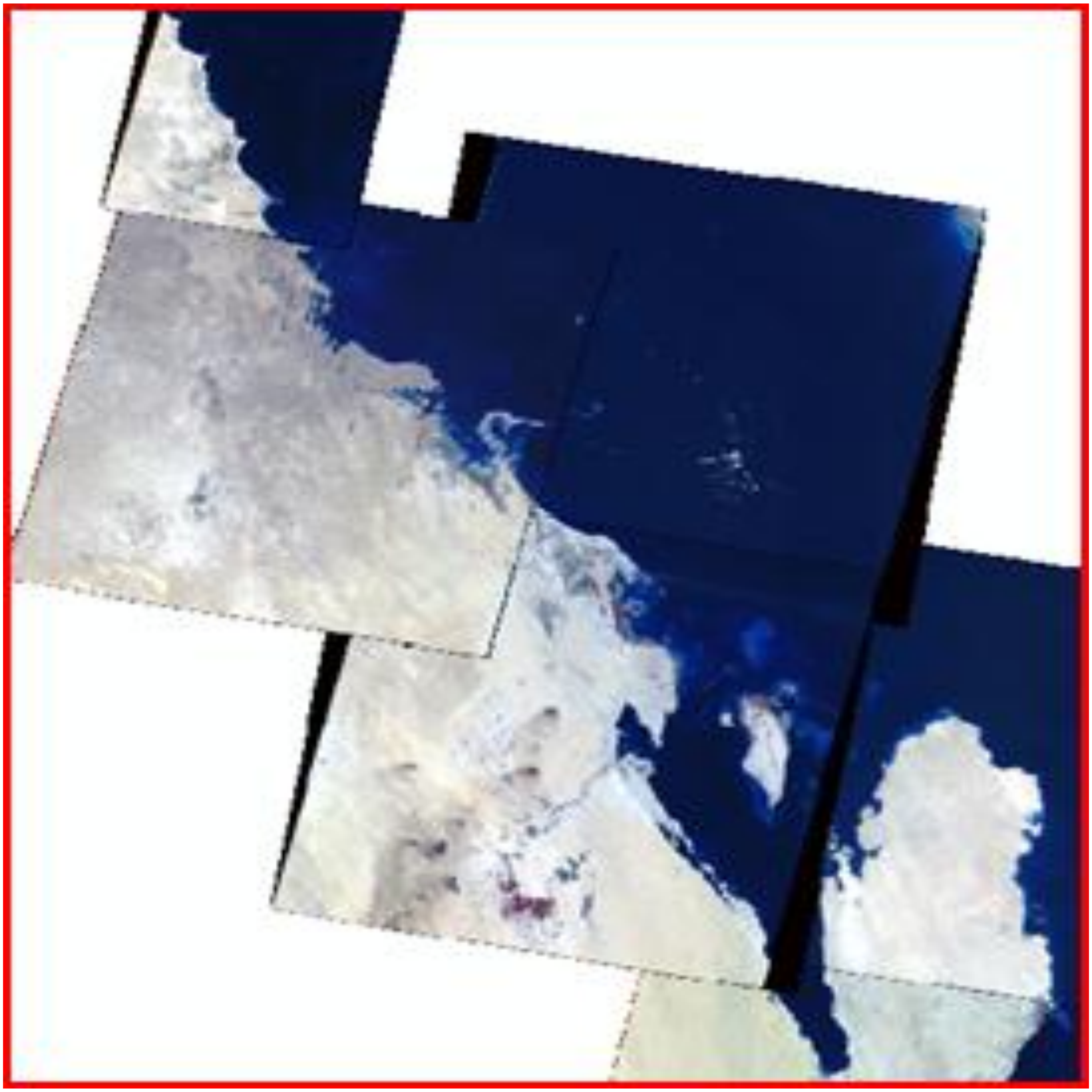

Figure (9): Using ArcView GIS to co-register and mosaic different satellite images of 1973.


Figure (10): Using ArcView GIS to co-register and mosaic different satellite images of 1995.

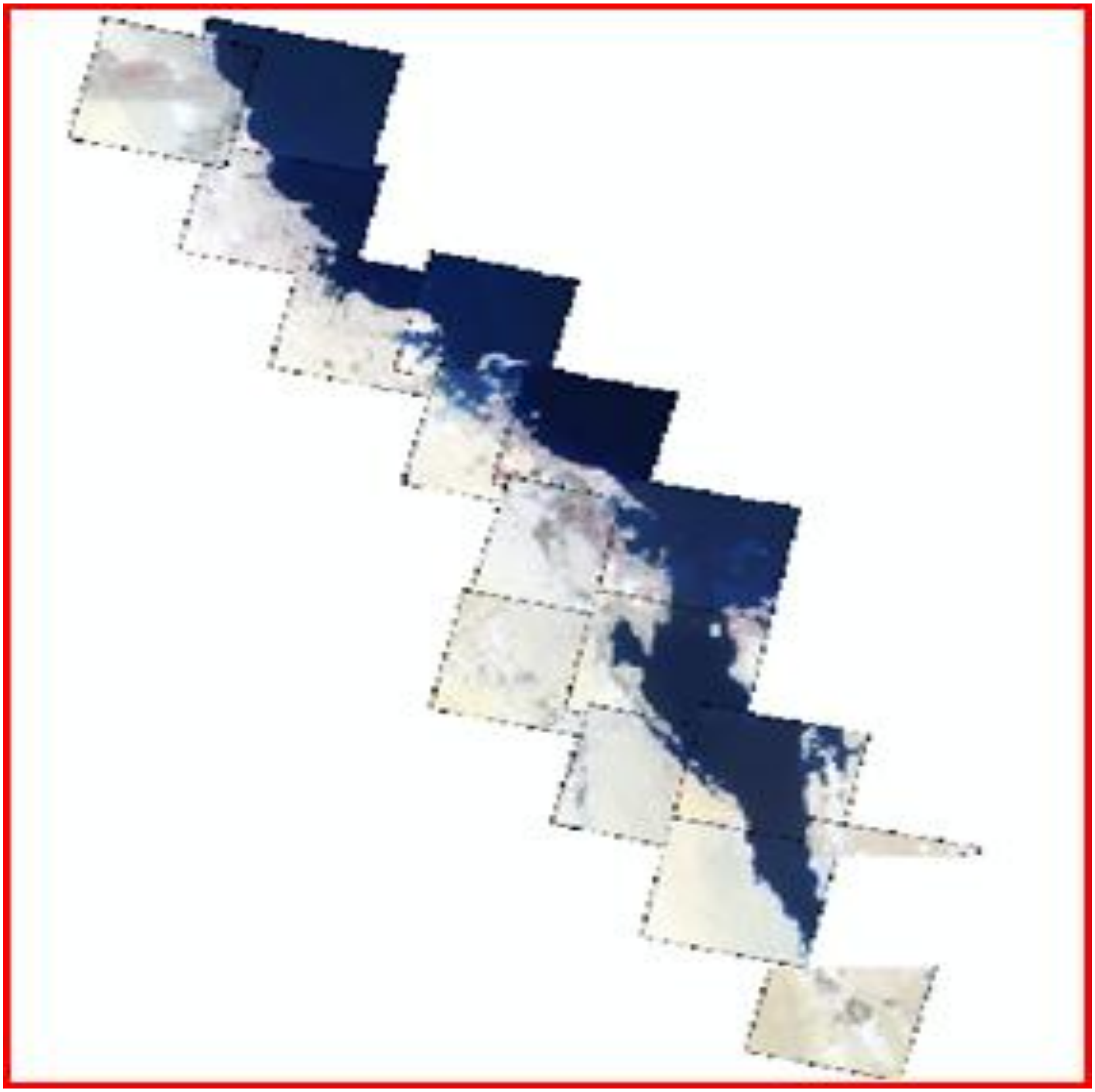
Figure (11): Using ArcView GIS to co-register and mosaic different satellite images of 2007.

### 6.3 Defining the Area of Interest

The definition of the study area boundaries was derived from the understanding that this area has to cover the same coast line in a zone that overlaps with each different timing costal images and the environmental Biotype map of Tarut bay.

A subset operation was conducted on the Landsat scenes covering the area of interest to produce only these portions covering the area of interest. Figure (12, 13, & 14) shows the original three scenes as well as the color resultant subset covering the area of interest.

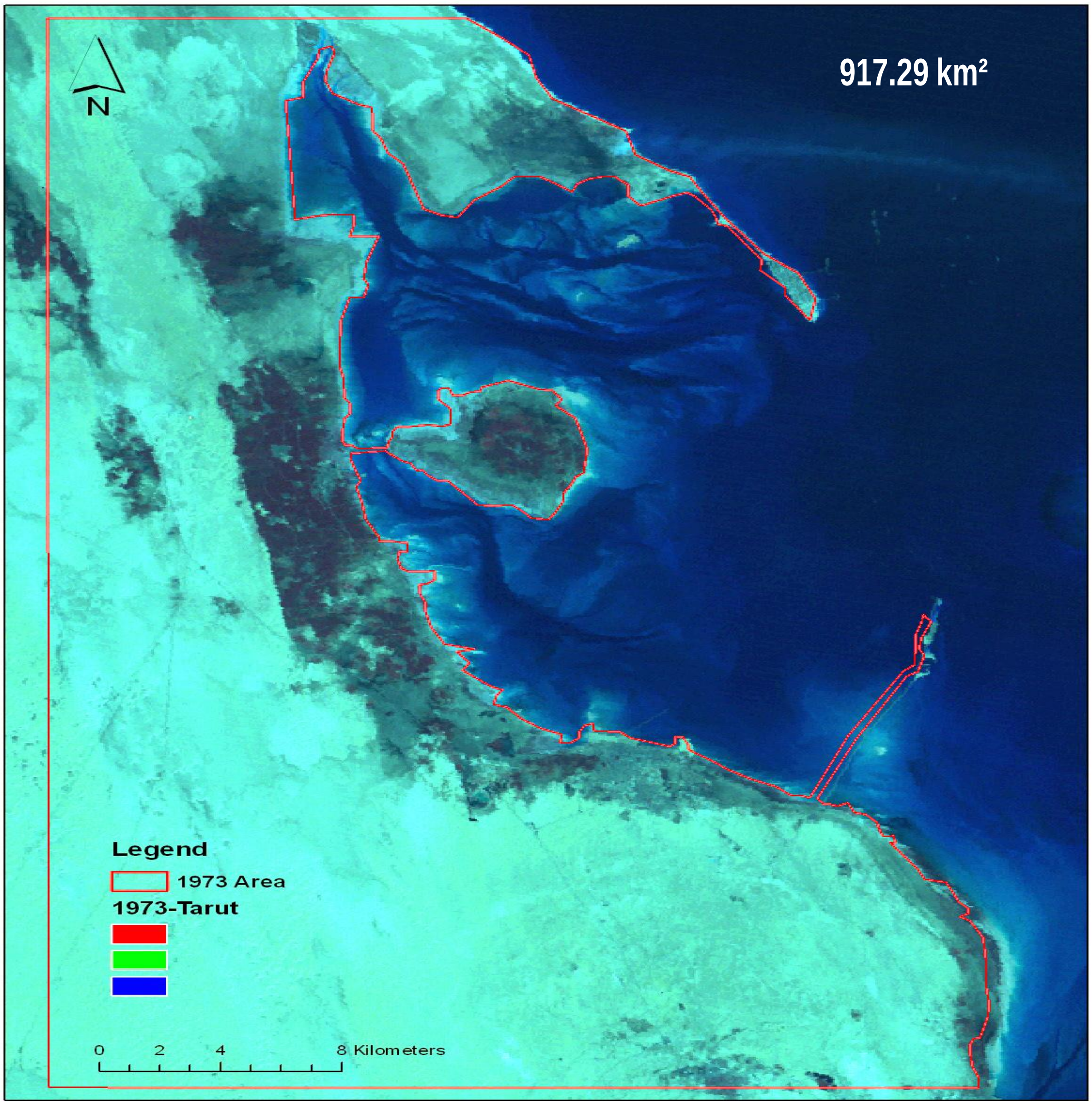


Figure (12): Landsat scenes covering the area of study and their subset into a new dataset 1973.


Figure (13): Landsat scenes covering the area of study and their subset into a new dataset 1995.

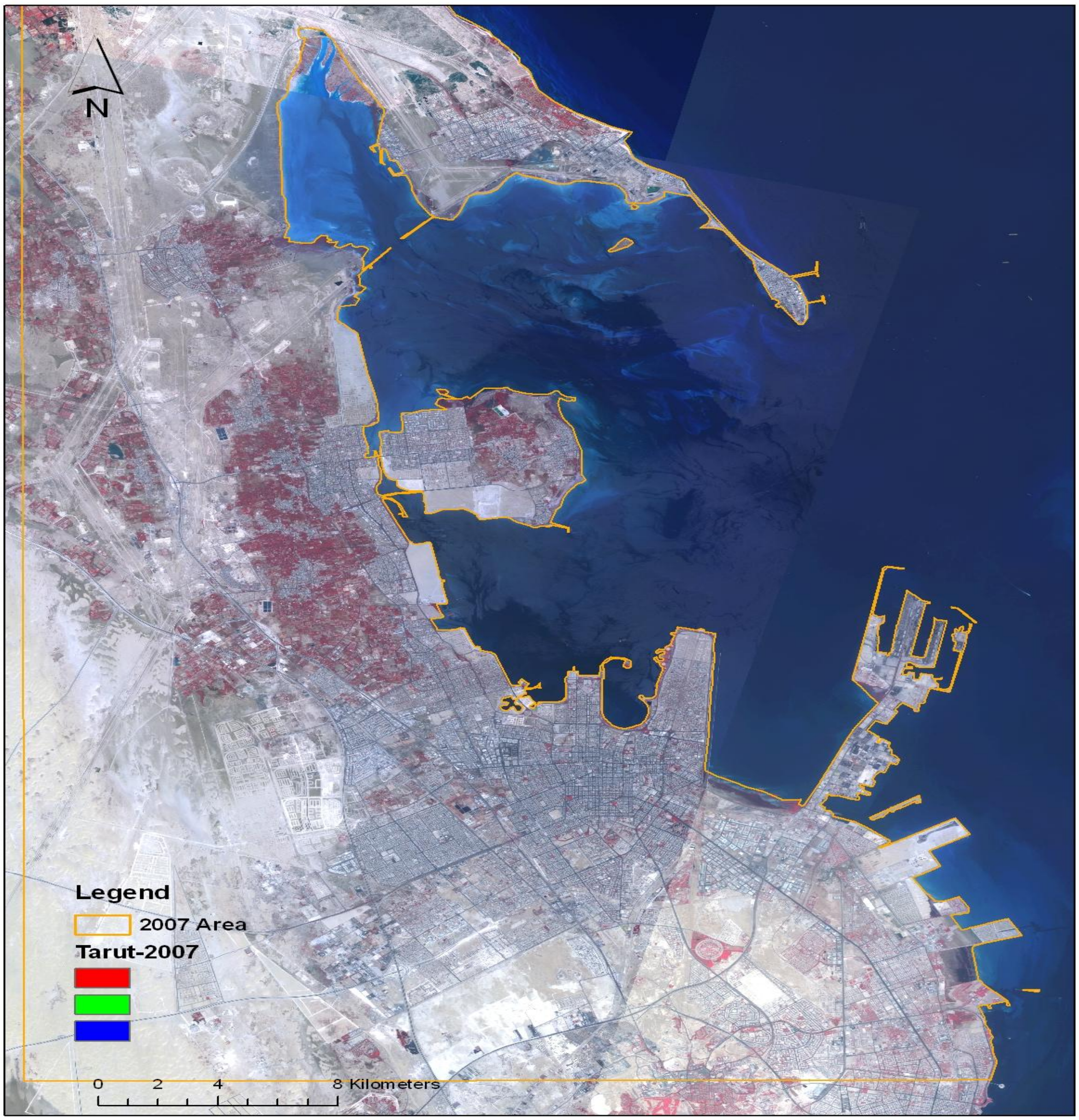


Figure (14): Landsat scenes covering the area of study and their subset into a new dataset 2007.

## 6.4 Reclaimed Area Calculation Procedure

In this study we utilized different software to quantify the reclaimed land within Tarut Bay area and below points summarize the calculation procedure steps.

- The pictures for all satellite images were uploaded into the ERDAS ER mapper software version 7.0.
- Geo-correction is made for uncorrected images.
- Images were aligned with each other to construct whole coastline seen to eliminate any overlapping.
- Every image was uploaded to the ESRI Arc GIS version 9.0 as single layer.
- Images were aligned again in GIS to construct whole coastline seen and prepare the area of interest for area digitizing.
- The area of interest was digitized to contain the area as polygon using GIS tools.
- The polygon area for different images data were calculated in square kilometers and the reclaimed area for different dates were determined.

The below points summarize the exact procedure steps that being followed to calculate reclaimed land using the software's:

**Using the ER Mapper software:**

1. 2007 Spot images already geo-corrected.
2. 1973 images need geo-correction.
    a. Open both images (one of coast line 2007 and same coordinates from 1973 or 1995 image).
    b. From the ER mapper tool bar choose "process icon", then Geocoding wizard.
    c. Open file of any image (ex; 176-42-1973).
    d. From polynomial setup, choose Linear as calculated.
    e. From GCP setup, select or mark Geocoded image, then open file and get spot image (ex; 152-297-2007) then press ok.
    f. Then do GPC edit (five widows of corrected and uncorrected images will pop up on the screen).
    g. Select two points from each image (2007 and 1973).
    h. To add extra points tap on "GPC +" button (select at least 15 points).
    i. Then choose Rectify button and specify the output and save the file as (ex; 176-42 geo-corrected).
    j. Then choose rectification process and after that cancel.
    k. After rectification save section picture 73-sub-section tarut as geo tiff/tiff.

       Save them in G:\satellite data 73, 1995, 2007-subsection tarut.

**Using GIS Application software:**

1. Open ARC map.
2. Go to file; then add data 73.
3. Open data 2007.
4. Then you can switch between two layers or images.
5. You need to draw polygon for the images;
    a. Under tools choose Arc catalog.
    b. Then from file tool bar choose “new” then “shape file” take 73 image.
    c. Name; 73 images as 73-sub-tarut.
    d. Feature shape; polygon.
    e. Description; edit and import the same image file the “add”, then Apply, OK.
    f. Take 2007 image and repeat steps one to five.
    g. From file “add data” of arc catalog for 73.
        a. Start editing by marking the land then, from editor stop editing if you need, then save it.
        b. Then both polygons are ready for area calculation.
        **c.** From arc tool, then spatial statistical tools, then utilities, we can calculate the area.
        d. The area of polygon of the example in hand is as follow:

           Area (polygon) 1973= 917.29 km²

           Area (polygon) 2007= 1001.71 km²

           Result= 917.29 – 1001.71= 84.42 km²

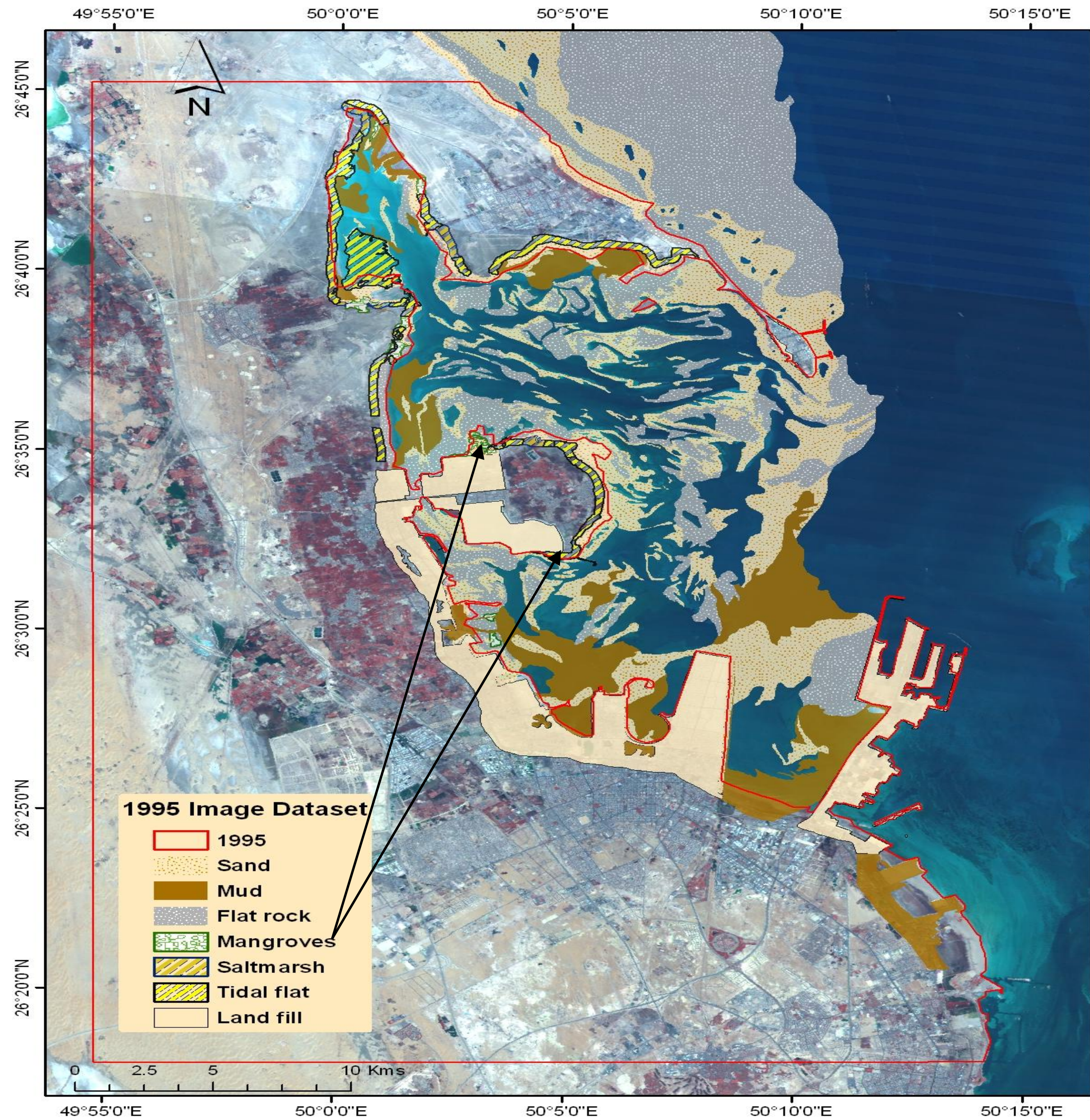

Figure (15): The mangrove impact due to reclamation activities after 1973 and up to 1995.

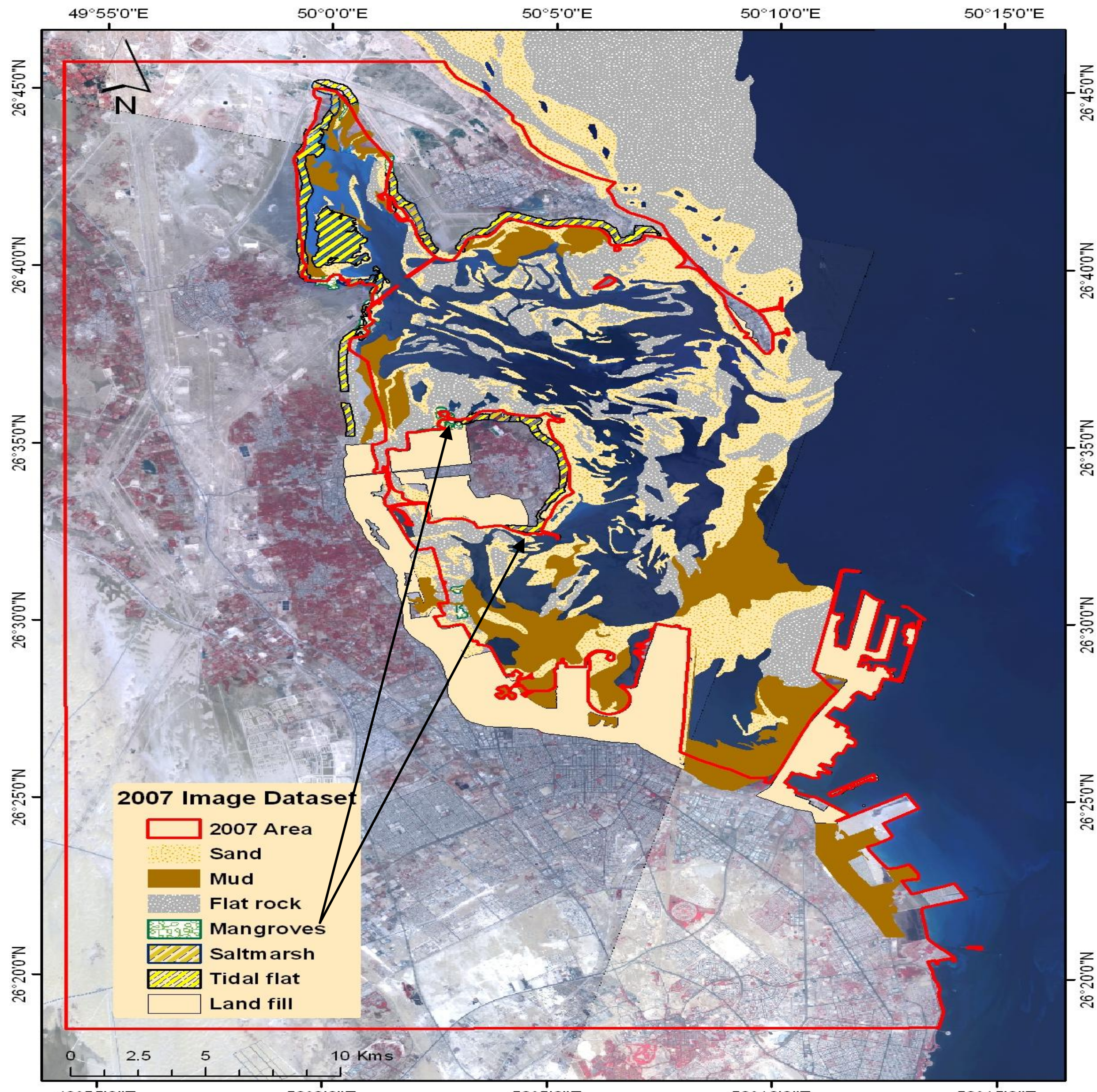


Figure (16): The mangrove impact due to reclamation activities after 1995 and up to 2007.

# CHAPTER 7

## 7.1 RESULTS

The quantification assessments of land reclamation along the east cost of Saudi Arabia was limited to the cost area toward Tarut Bay because of the major reclamation activities that took place since 1970 and also due to the availability of the environmental Biotype map for that area. Table 4 summarizes the area reclamation quantities and their usage for different period of time.

**Table 4**: Summary of land reclamation quantities and their usage.

| Reclamation Area | Year of land reclaimed | Land added $Km^2$ | Marine Habitat affected | Land use | Remarks (digitized subsection area $Km^2$) |
|---|---|---|---|---|---|
| Tarut Bay | 1973 | 0 | None | None | 917.29 |
| Tarut Bay | 1973---1995 | 83.68 | Mangrove | Residential | 1000.97 |
| Tarut Bay | 1995---2007 | 84.42 | Mangrove | Residential | 1001.71 |

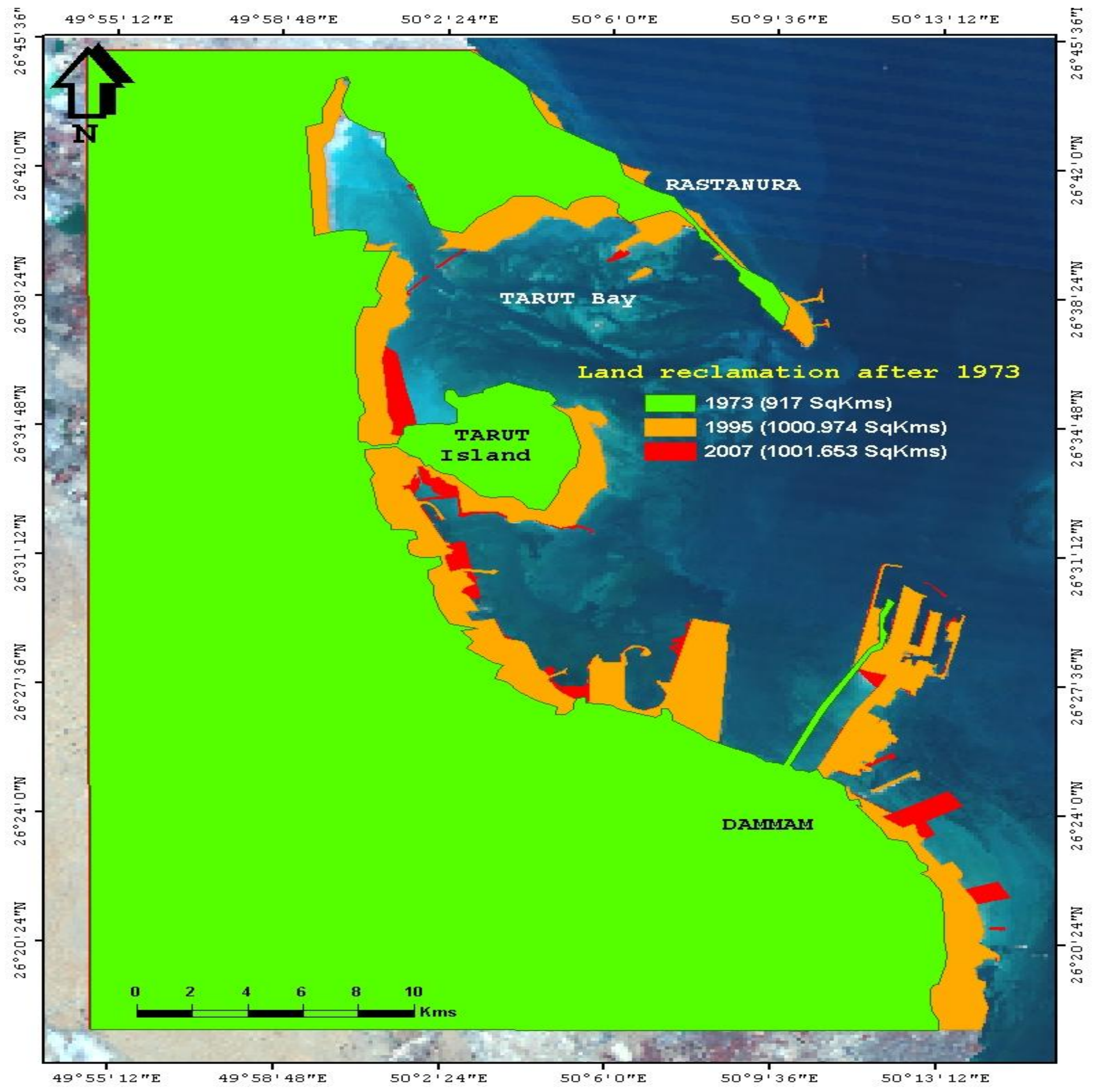

Figure (17): Highlight the land reclamation activities from 1973 to 2007

## 7.2 CONCLUSION

This study shows and quantifies the amount of reclaimed land at the study area site of Tarut bay of the Arabian Gulf in the eastern province of the Kingdom of Saudi Arabia. The total land that has been reclaimed within Tarut Bay area since 1973 up to November 2007 were found to be 84.42 square kilometers ($Km^2$) which most of it were utilized for residential purposes.

The reclaimed land quantities were calculated base on subsection of couple of image datasets for Tarut bay, in which we first calculated the 1973 subsection then subtracted from the calculated subsections areas of the following 1995 and 2007 timing. And as tabulated above, the research study found out that the most of land reclamation activities were carry out before November, 1995.

The amount of reclaimed land due to reclamation activities since 1973 to 1995 was found to be around 83.68 square kilometers ($Km^2$) whereas the reclamation activities after November 1995 were found very little and the total reclaimed area up to 2007 were only 0.74 square kilometers ($Km^2$). In the other hand, the study also show some environmental consequences due to reclamation activities within Tarut bay area.

The superimpose of environmental biotype map of Tarut bay marine life with 1995 and 2007 reclaimed area show a clear and destructive impact on mangrove habitats that Tarut bay were very famous about as marked in (figures15 & 16). The results of the thesis study were aligned and confirmed with the recent study conducted by environmental protection department in Saudi

Aramco in which it indicated the destruction in mangrove habitat was estimated to 90% of the original mangrove ecosystems along the Gulf coast have been lost mostly as a result of coastal urban development. Also it indicated that the current estimate of mangrove habitat within the Saudi Arabian territories of the Gulf is 412 ha, comprising 55 ha of plantation (1).

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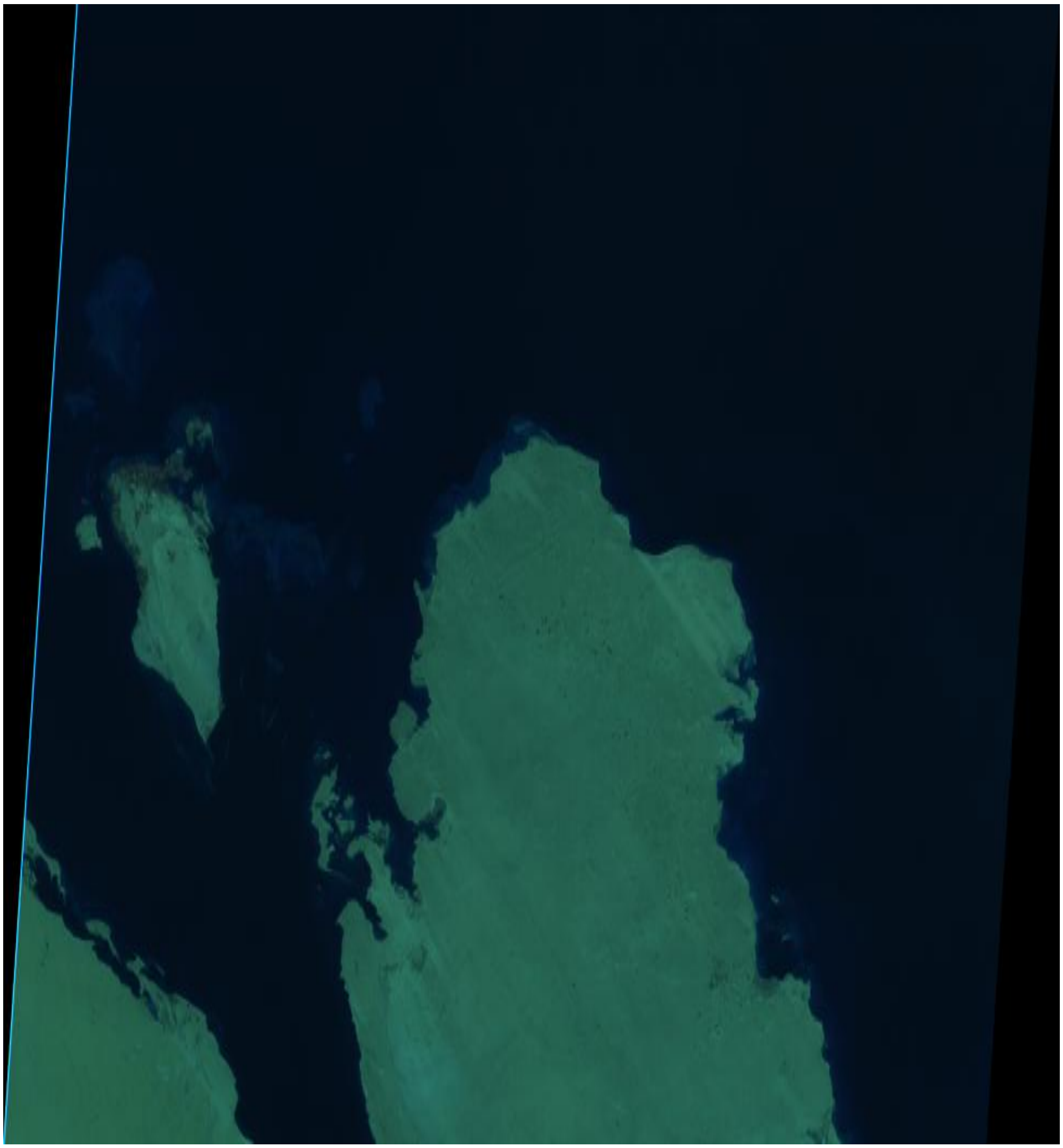
# APPENDICES

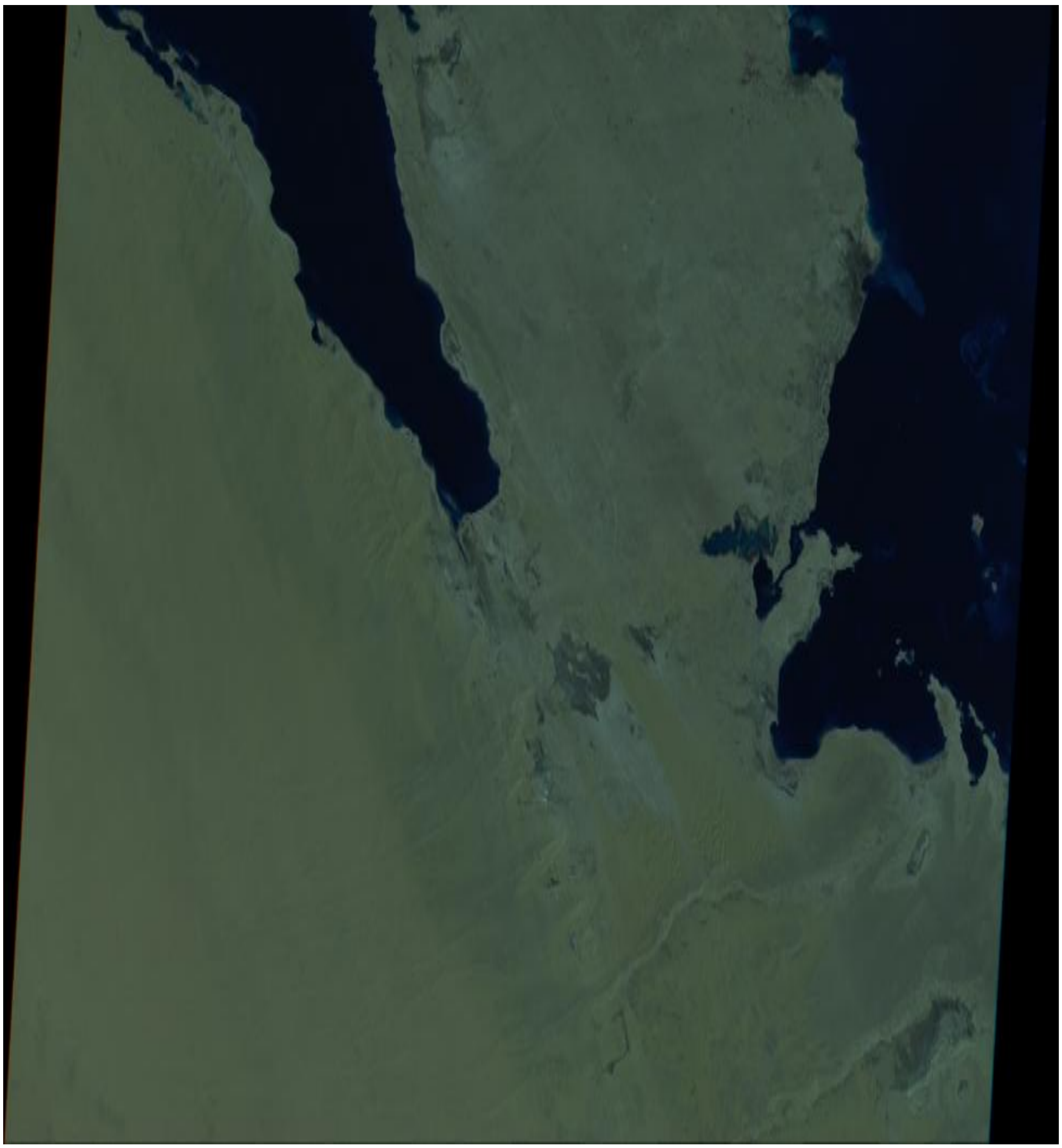
## Appendix 1

## Worldwide Reference System Images (WRSI) of Eastern Cost of Saudi Arabia, 1973 Shore Line



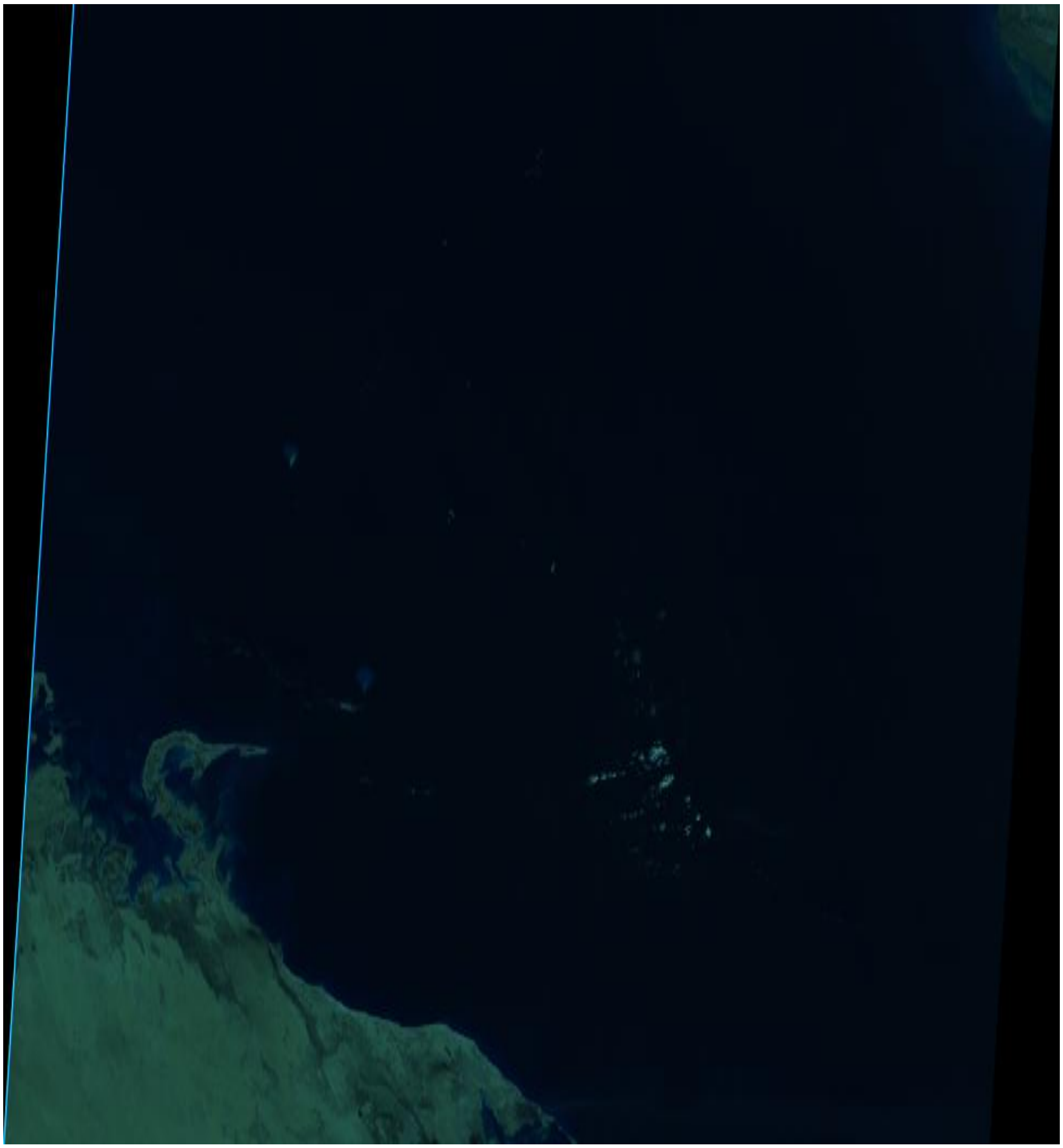
WRSI: Path 175- Row 42

October 1973



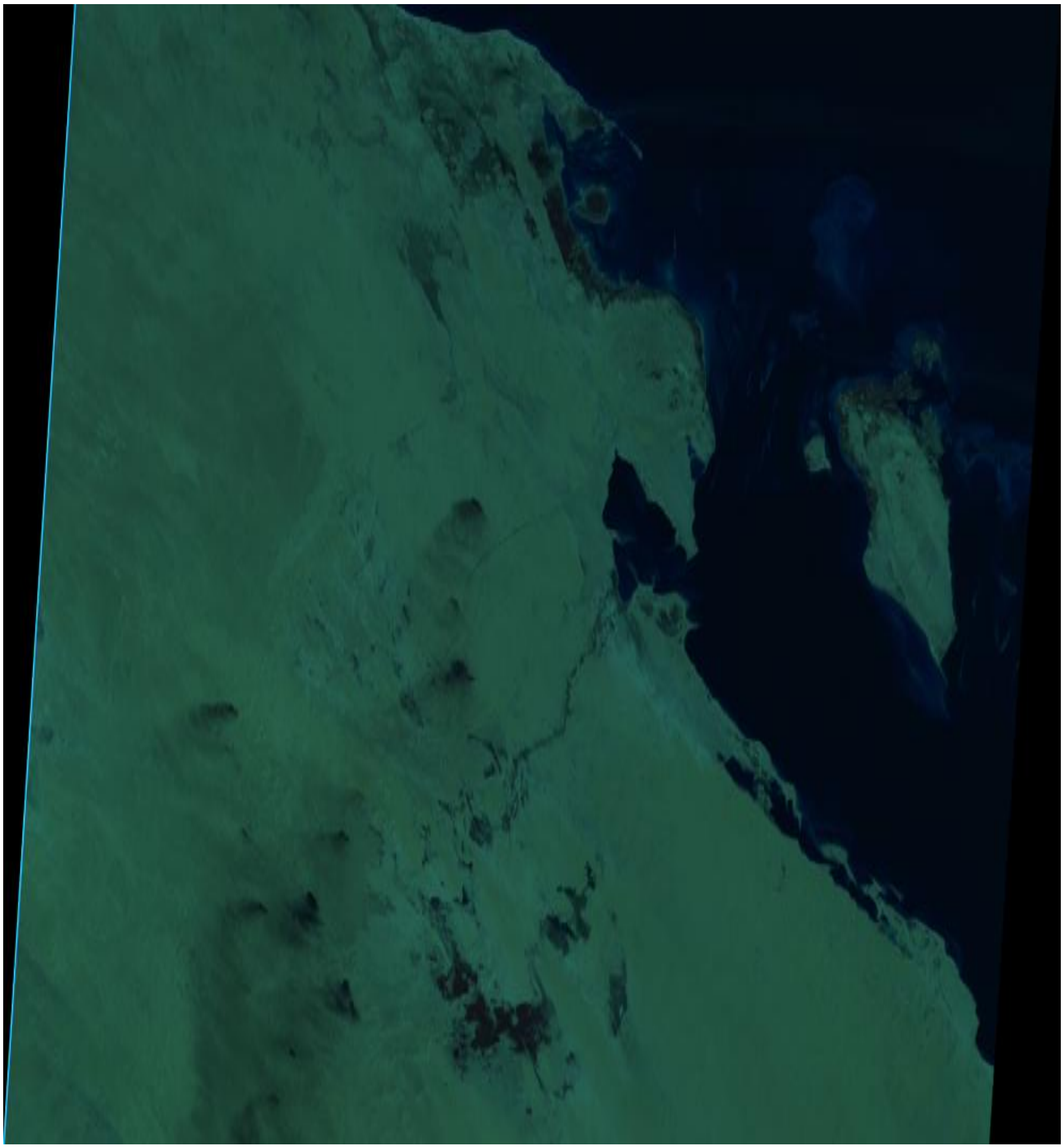
WRSI: Path 175- Row 43

January 1973



WRSI: Path 176- Row 41

January 1973

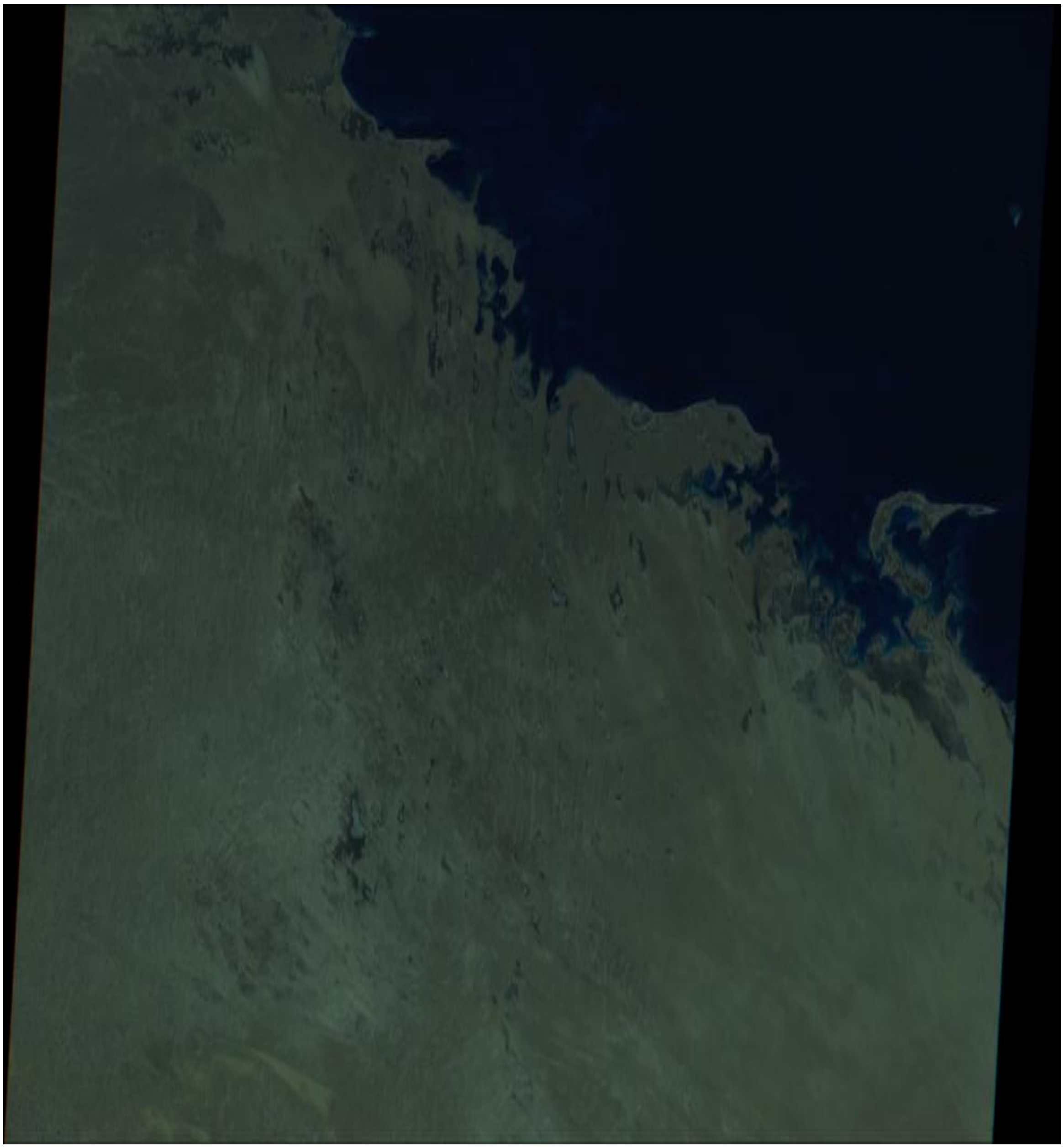


WRSI: Path 176- Row 42

January 1973

WRSI: Path 177- Row 40

January 1973



WRSI: Path 177- Row 41

January 1973

## Appendix 2

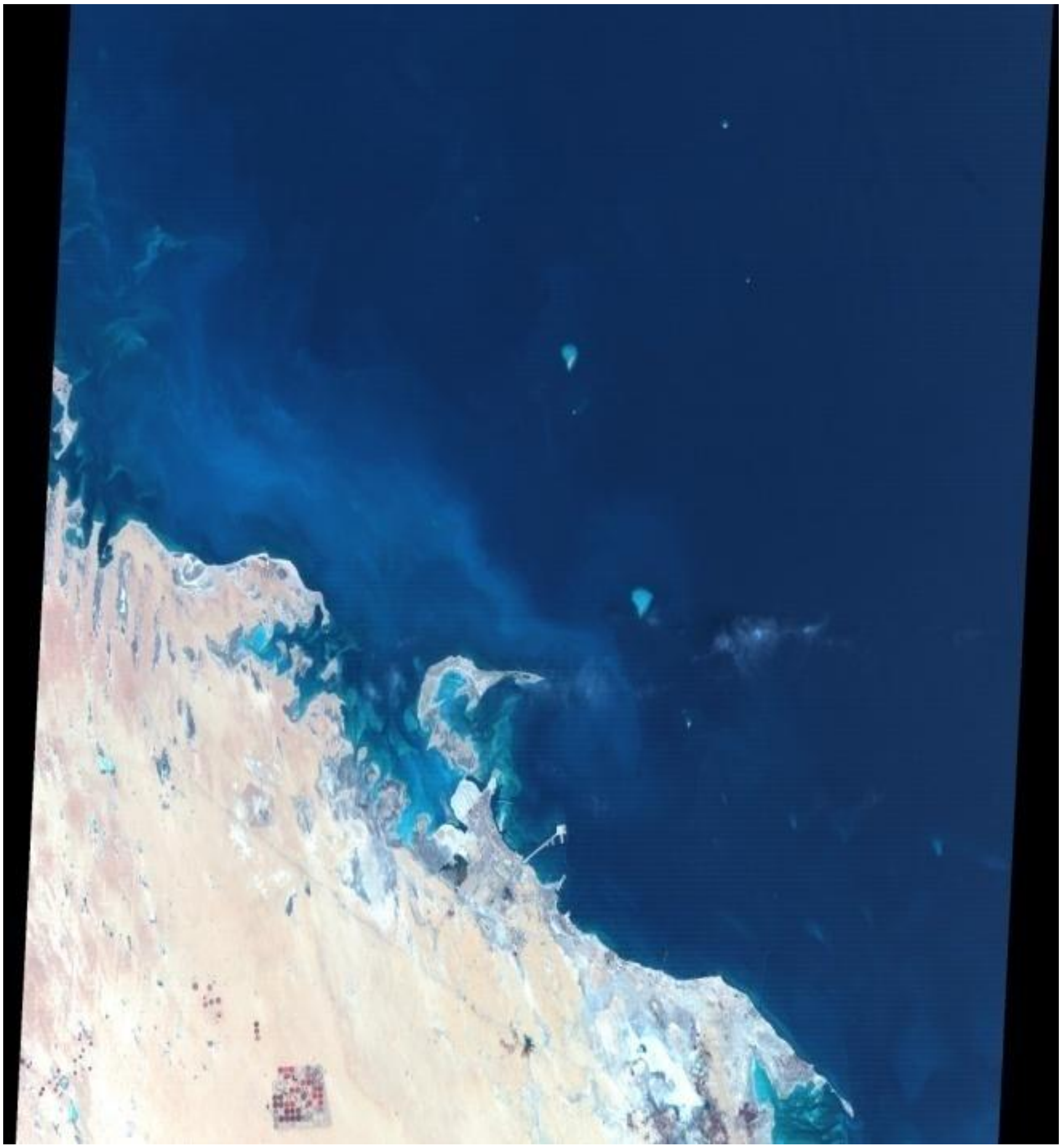
## Worldwide Reference System Images (WRSI) of Eastern Cost of Saudi Arabia, 1995 Shore Line

WRSI: Path 163- Row 42

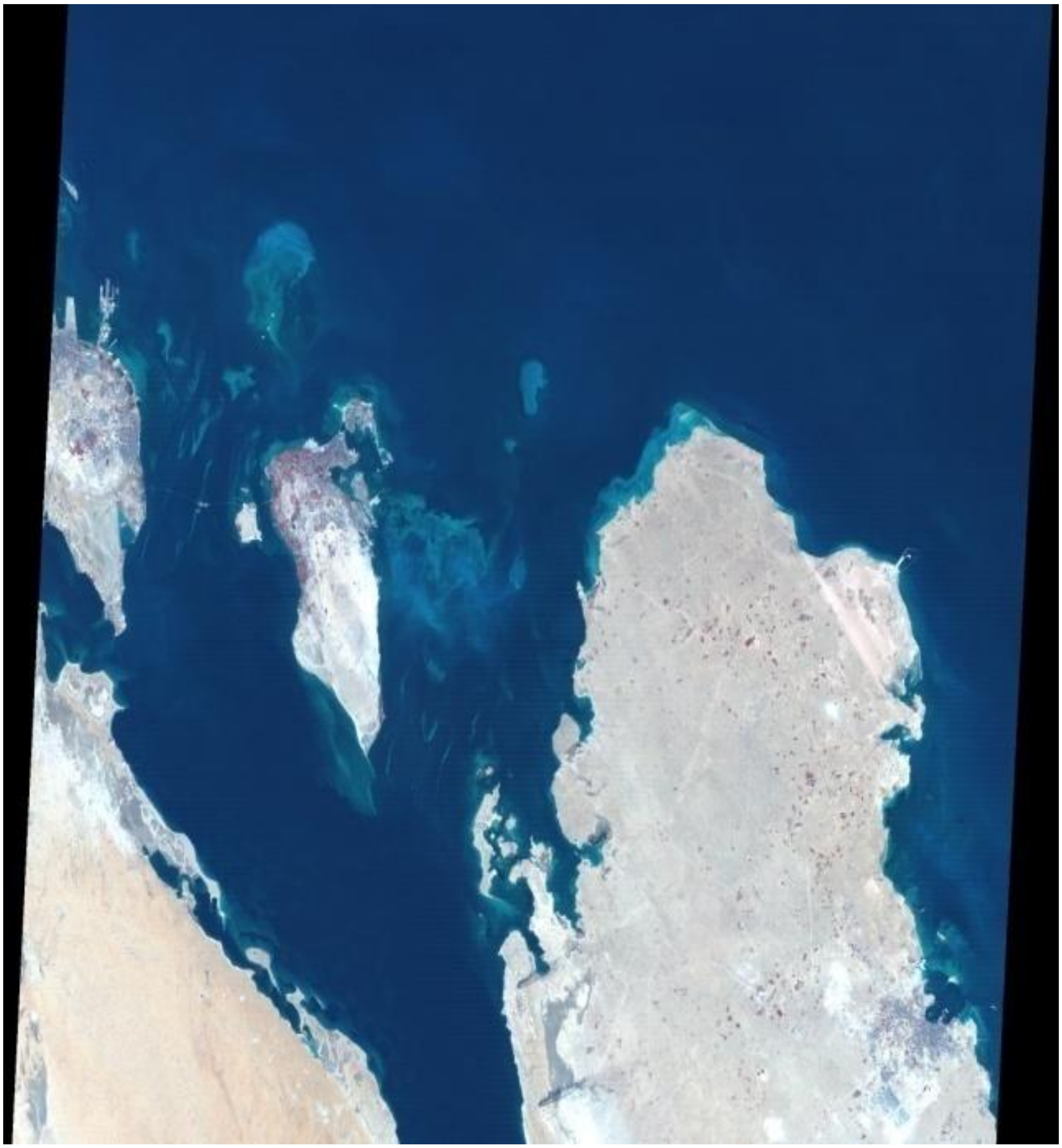
November 1995

WRSI: Path 163- Row 43

November 1995

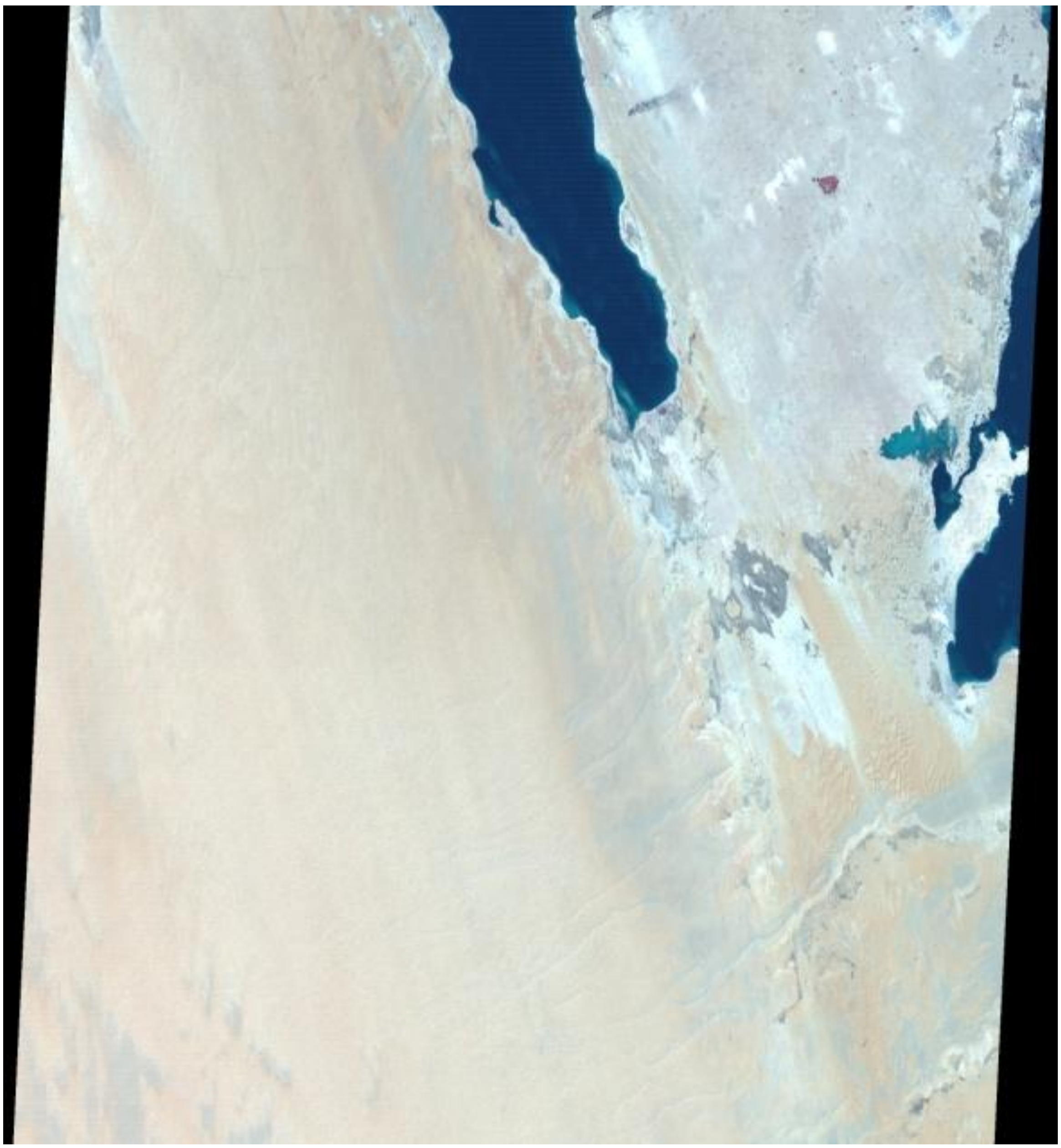


WRSI: Path 164- Row 41
April 1995



WRSI: Path 164- Row 42

April 199

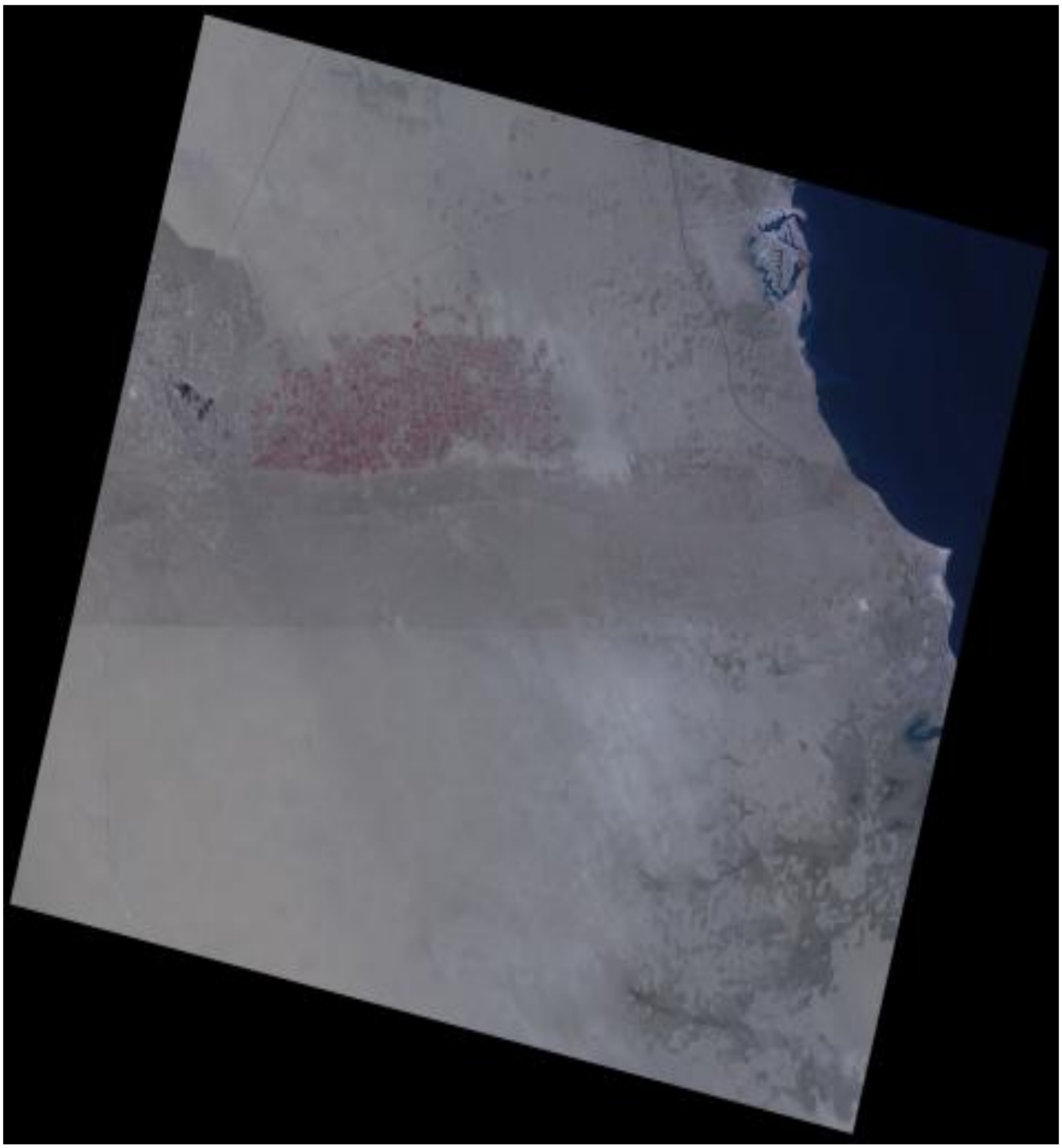


WRSI: Path 165- Row 40

August 1995

## Appendix 3

## Worldwide Reference System Images (WRSI) of Eastern Cost of Saudi Arabia, 2007 Shore Line

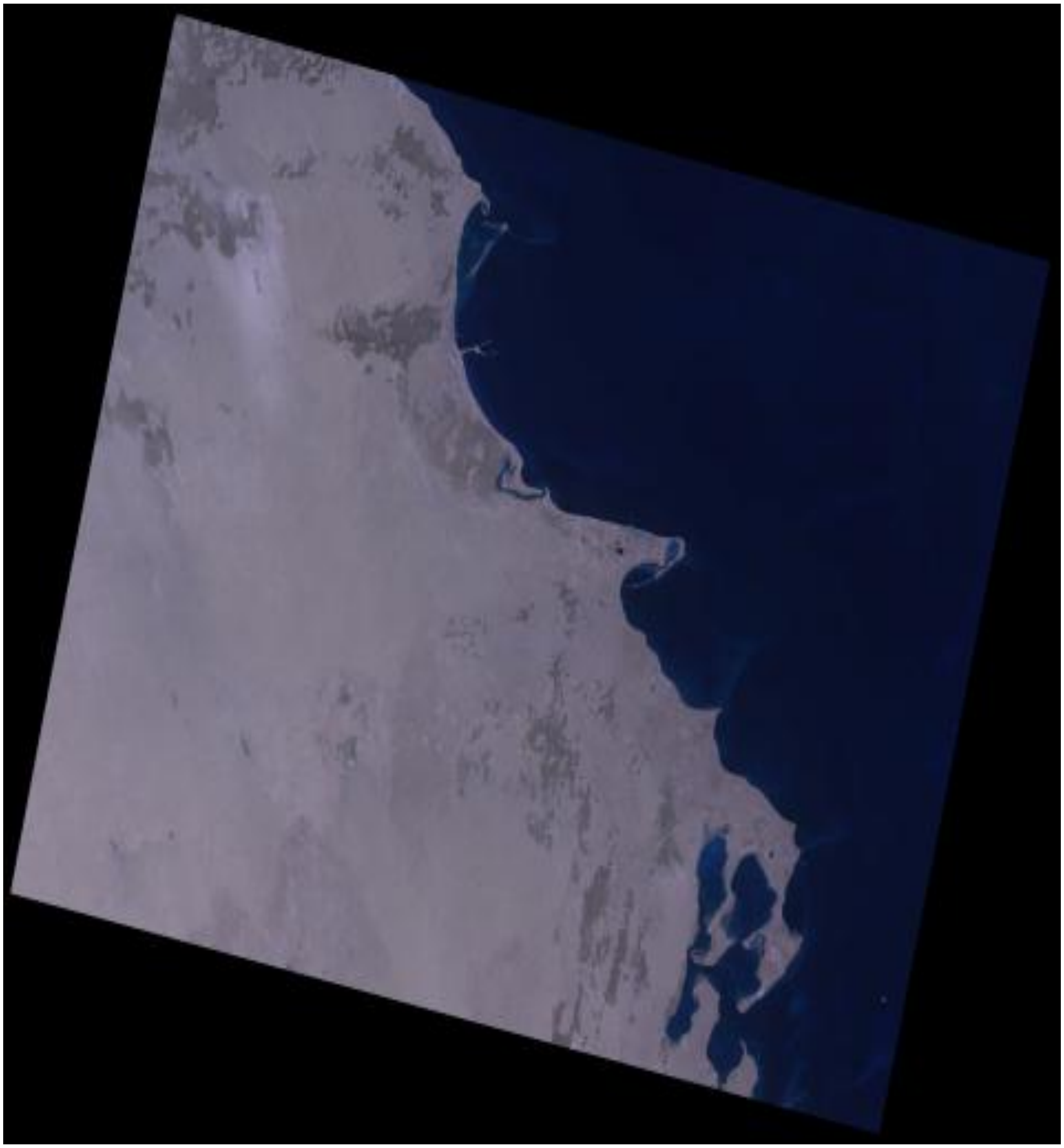


WRSI: Path 147- Row 293

2007

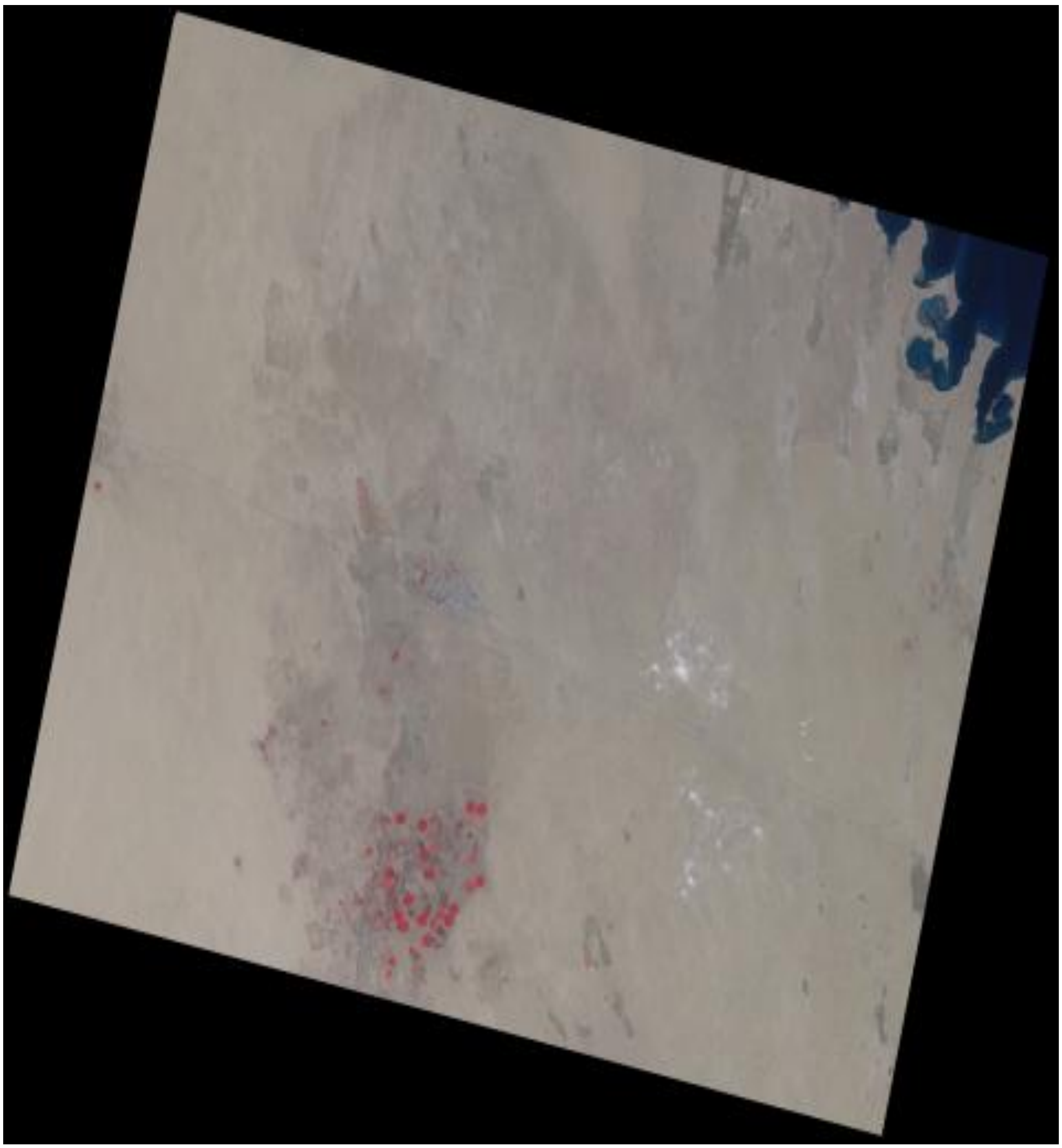
WRSI: Path 148- Row 293

2007



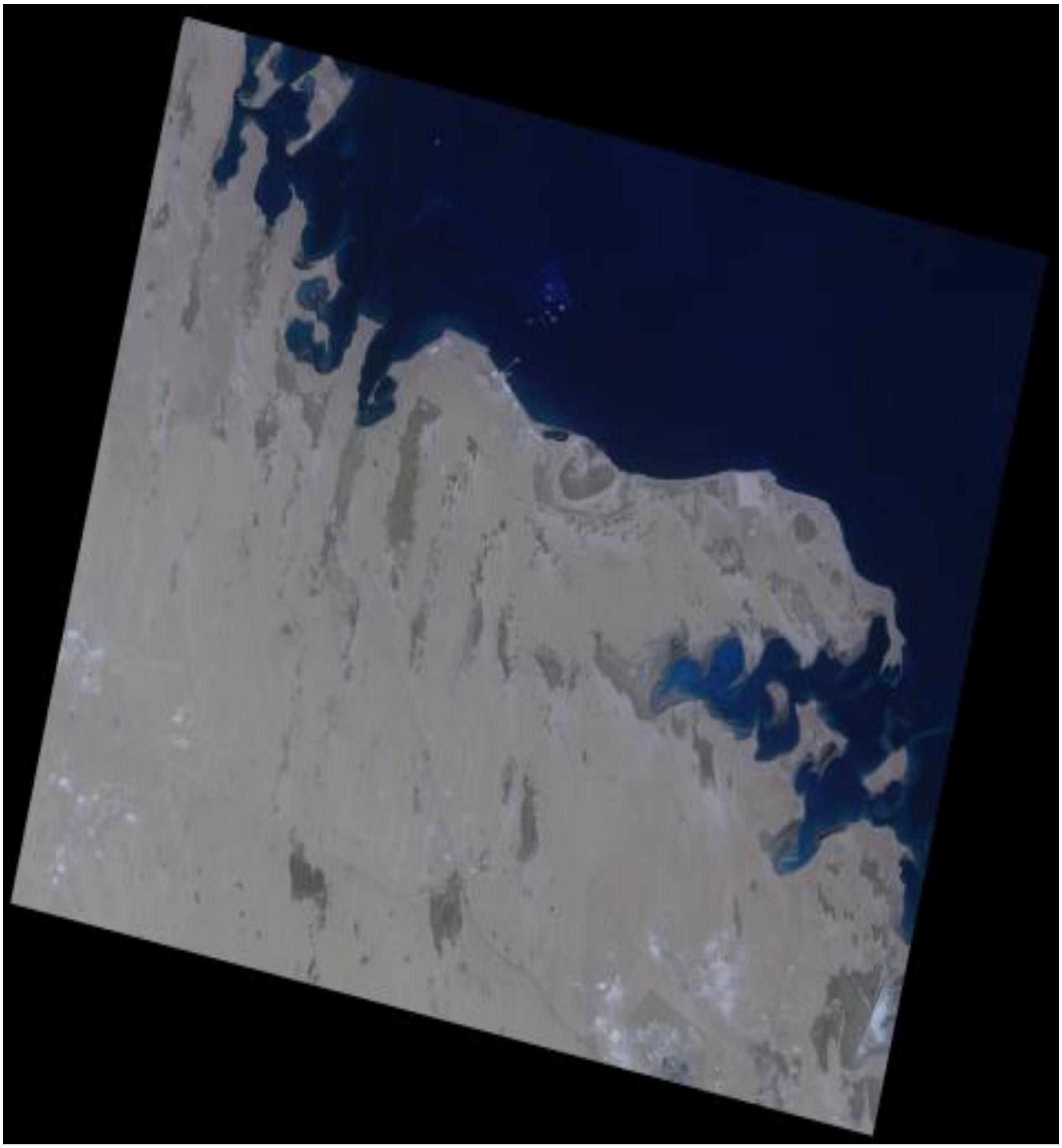
WRSI: Path 149- Row 294

2007



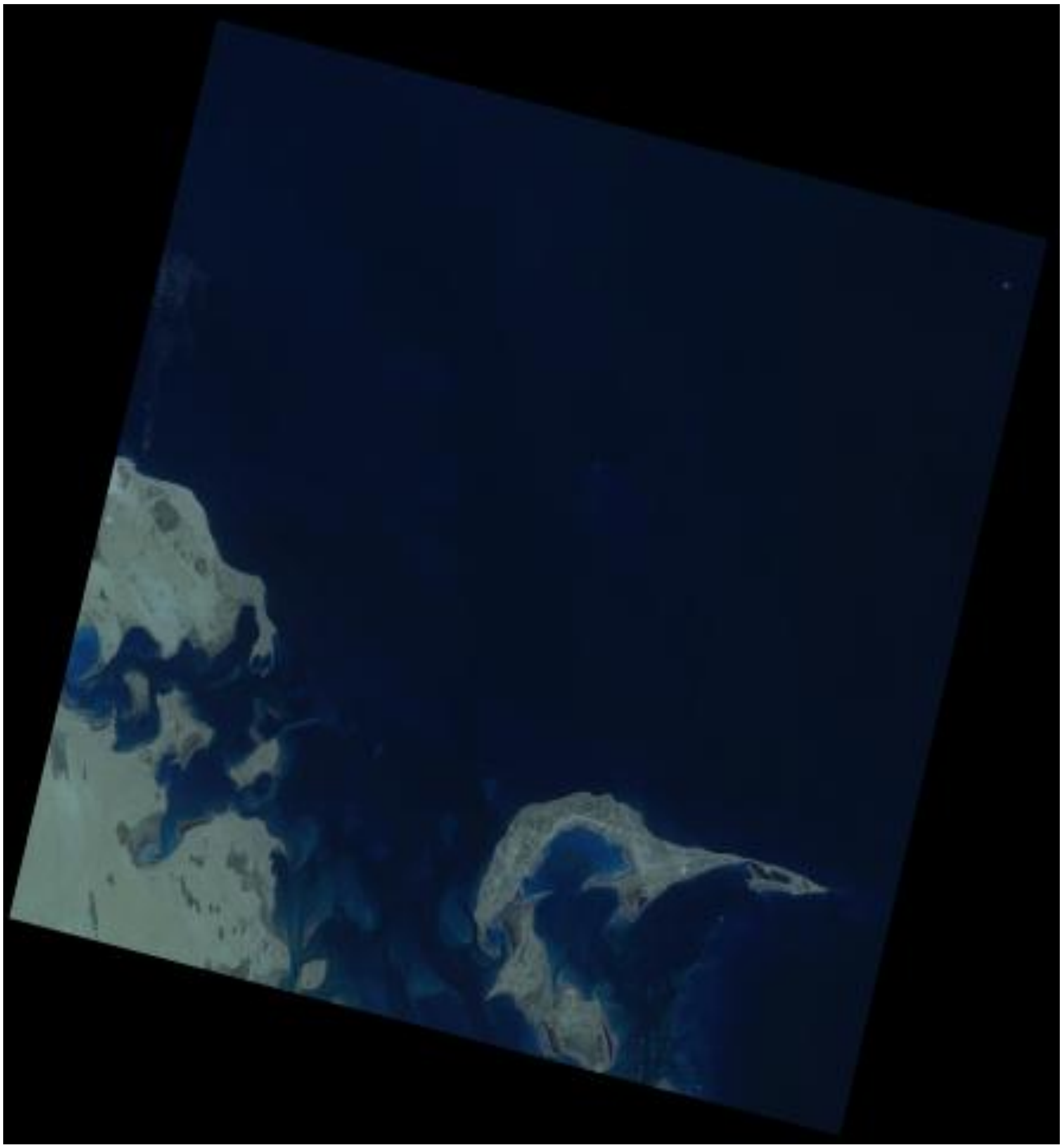
WRSI: Path 149- Row 295

2007



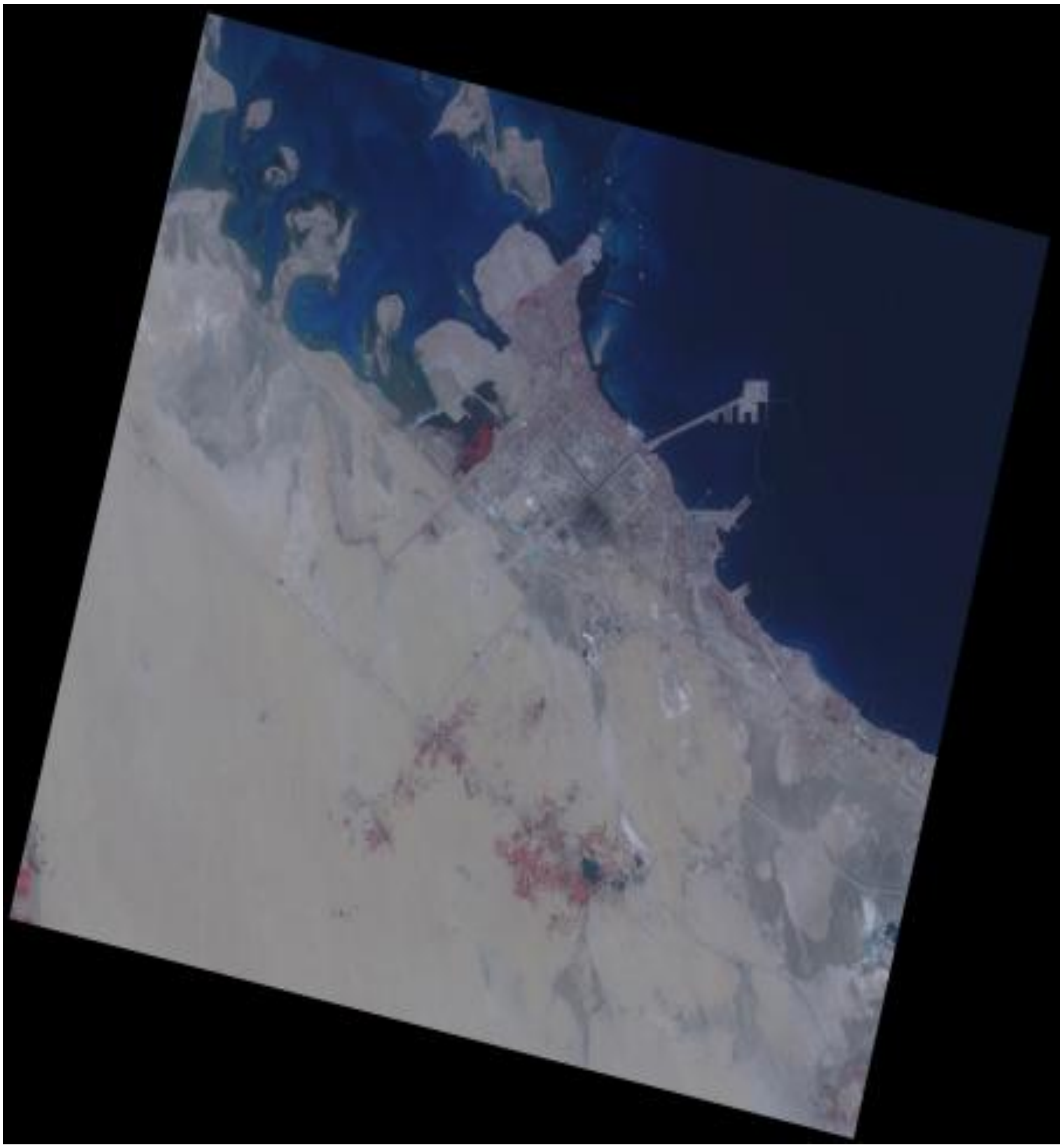
WRSI: Path 150- Row 295

2007



WRSI: Path 151- Row 295

2007

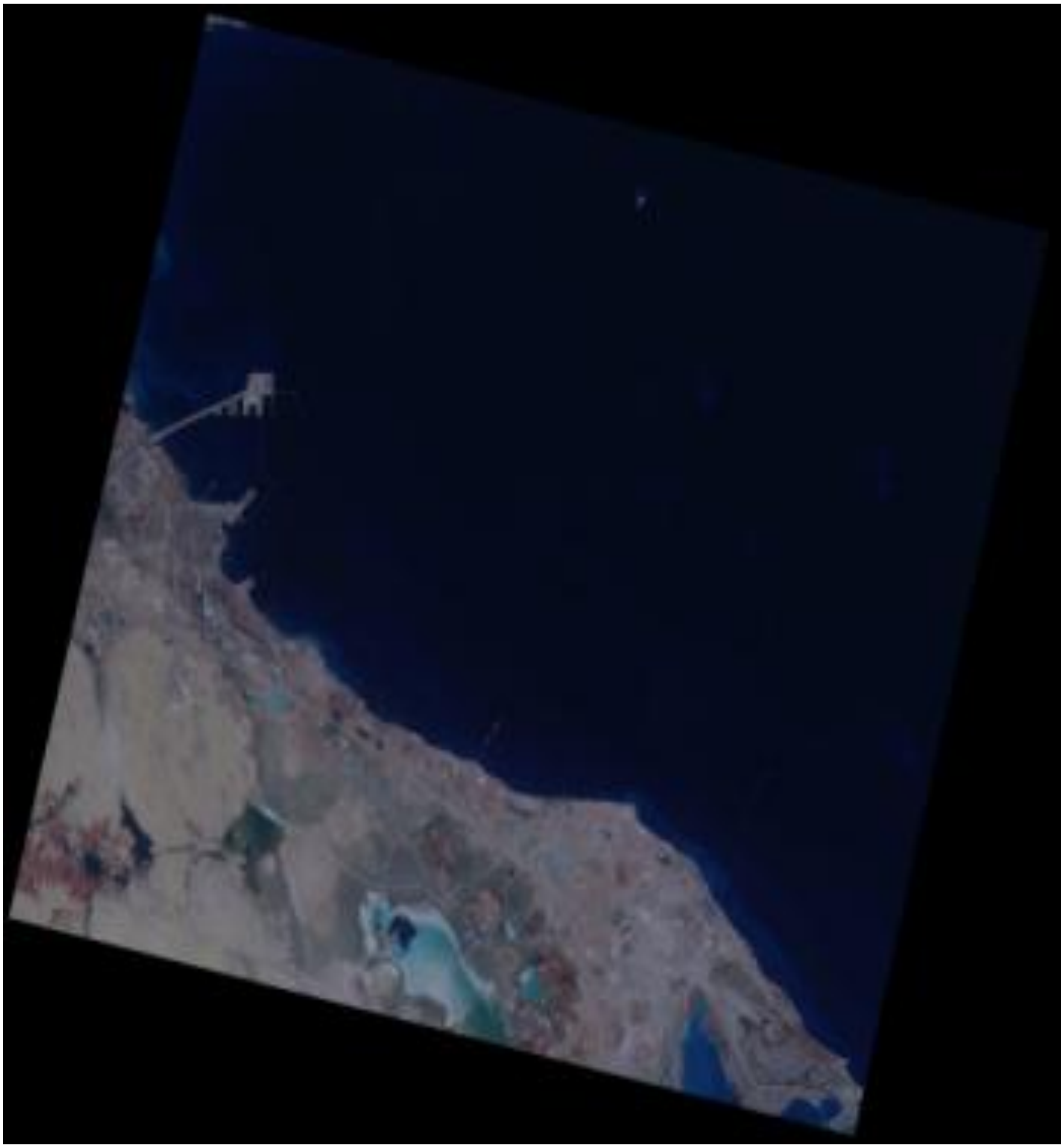


WRSI: Path 151- Row 296

2007

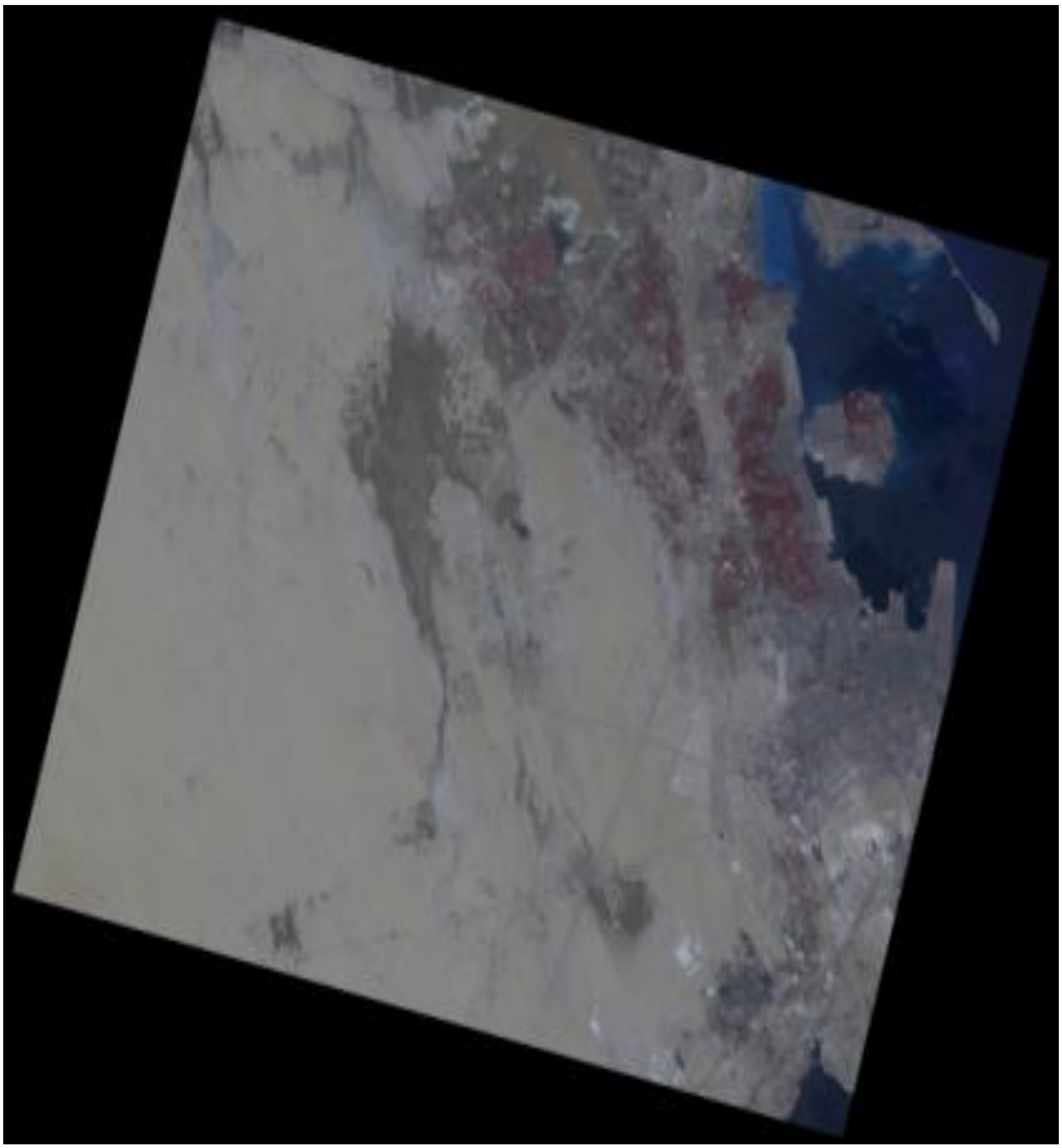
WRSI: Path 151- Row 297

2007



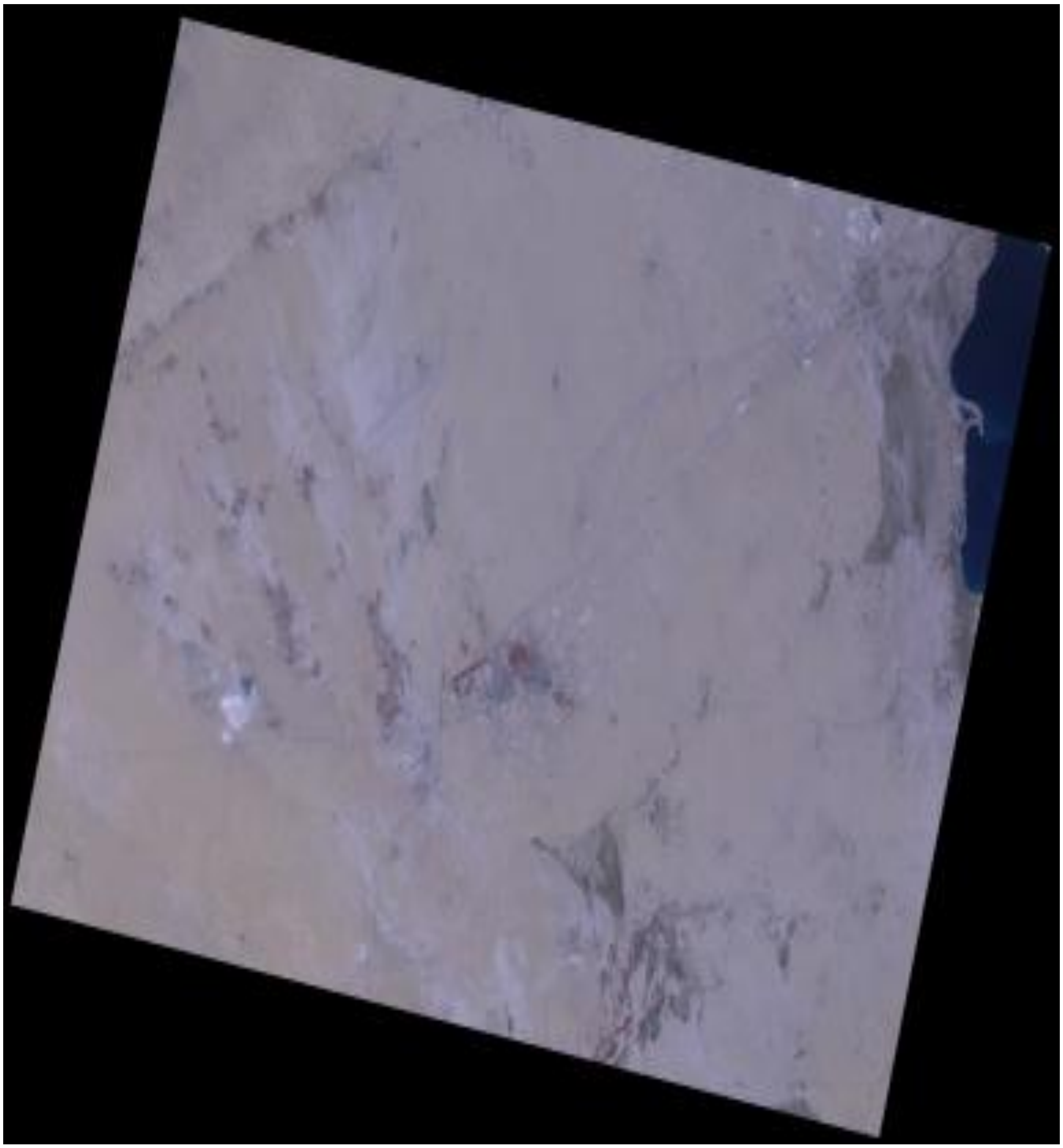
WRSI: Path 152- Row 296

2007



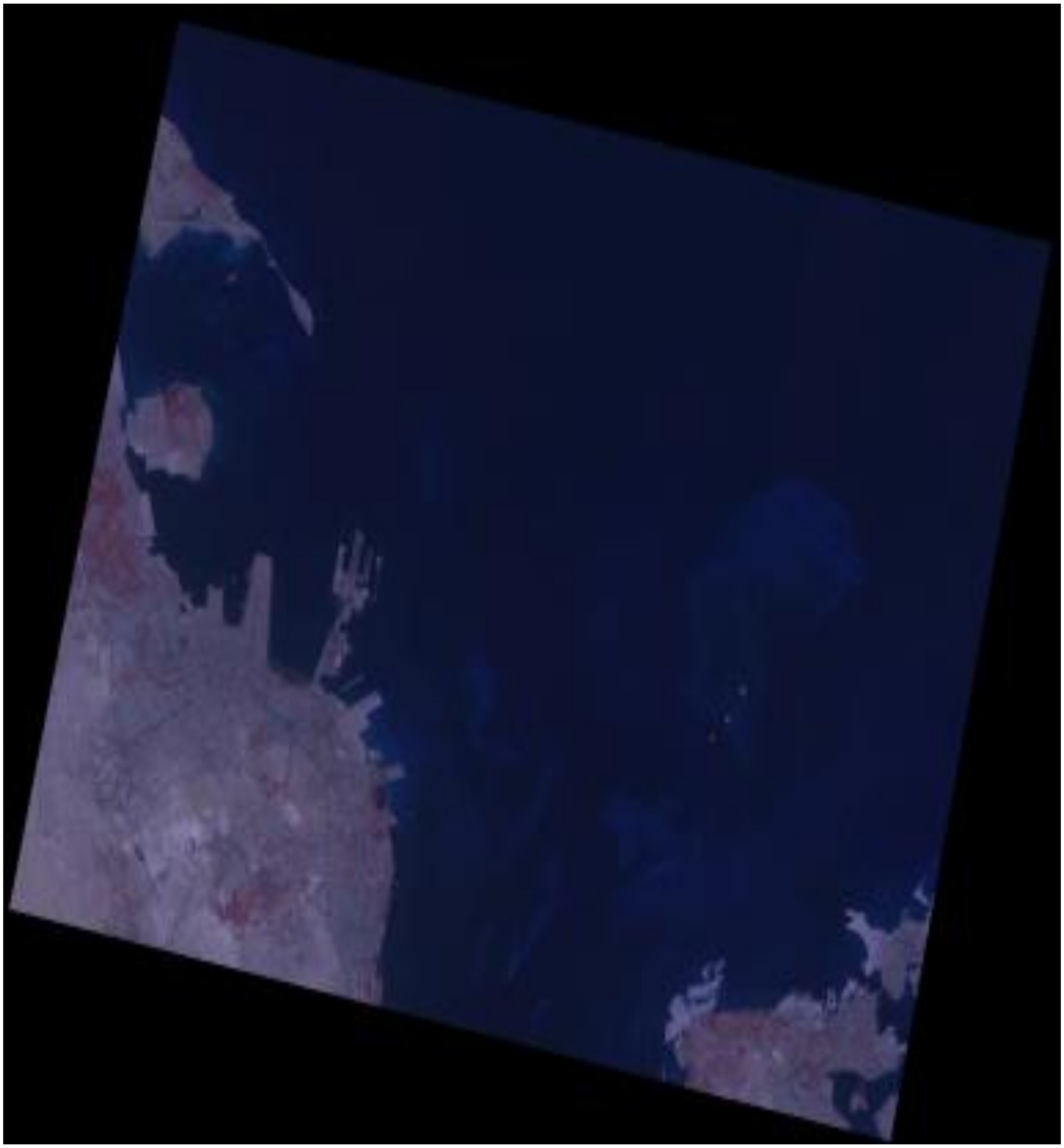
WRSI: Path 152- Row 297

2007



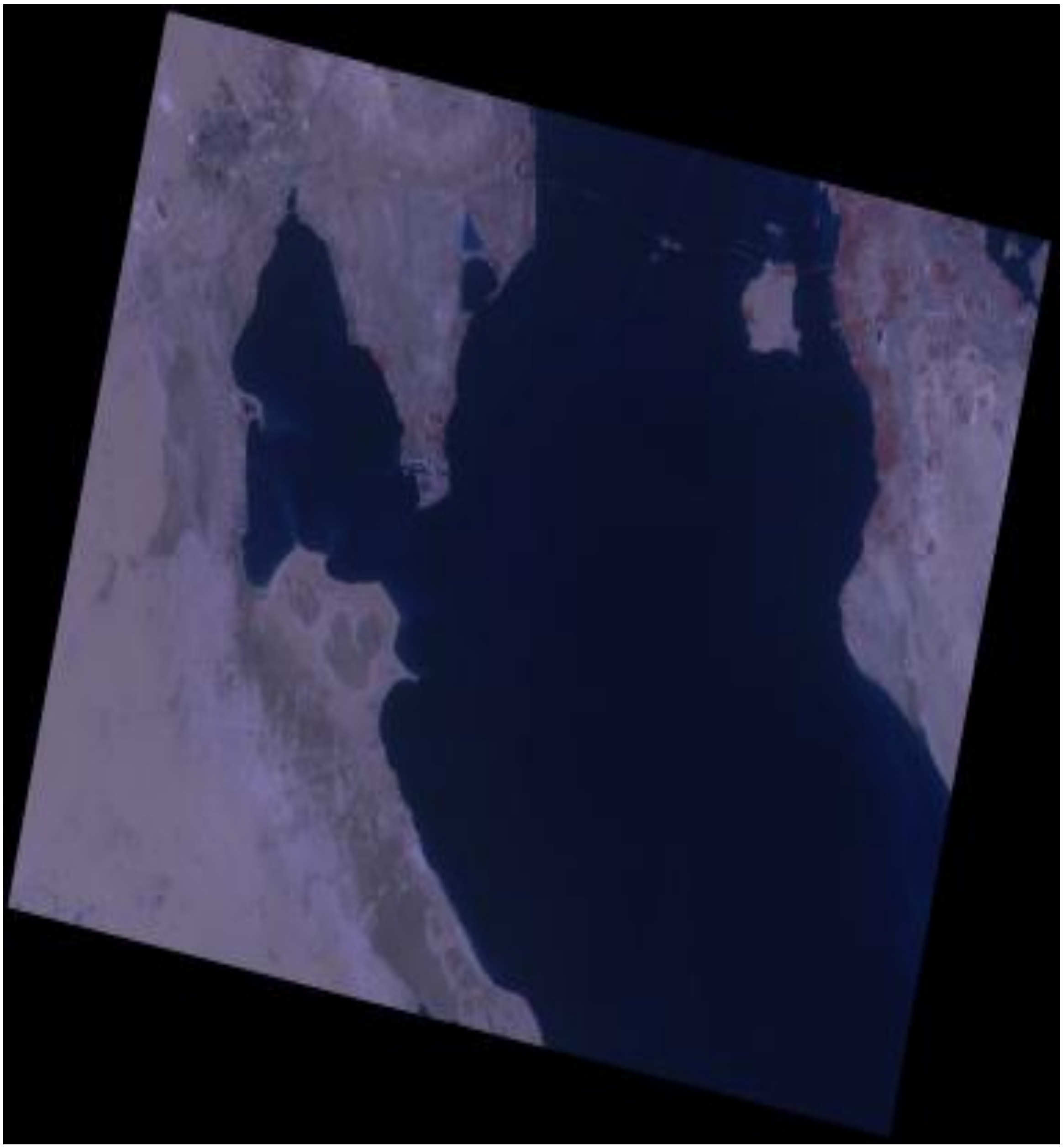
WRSI: Path 152- Row 298

2007



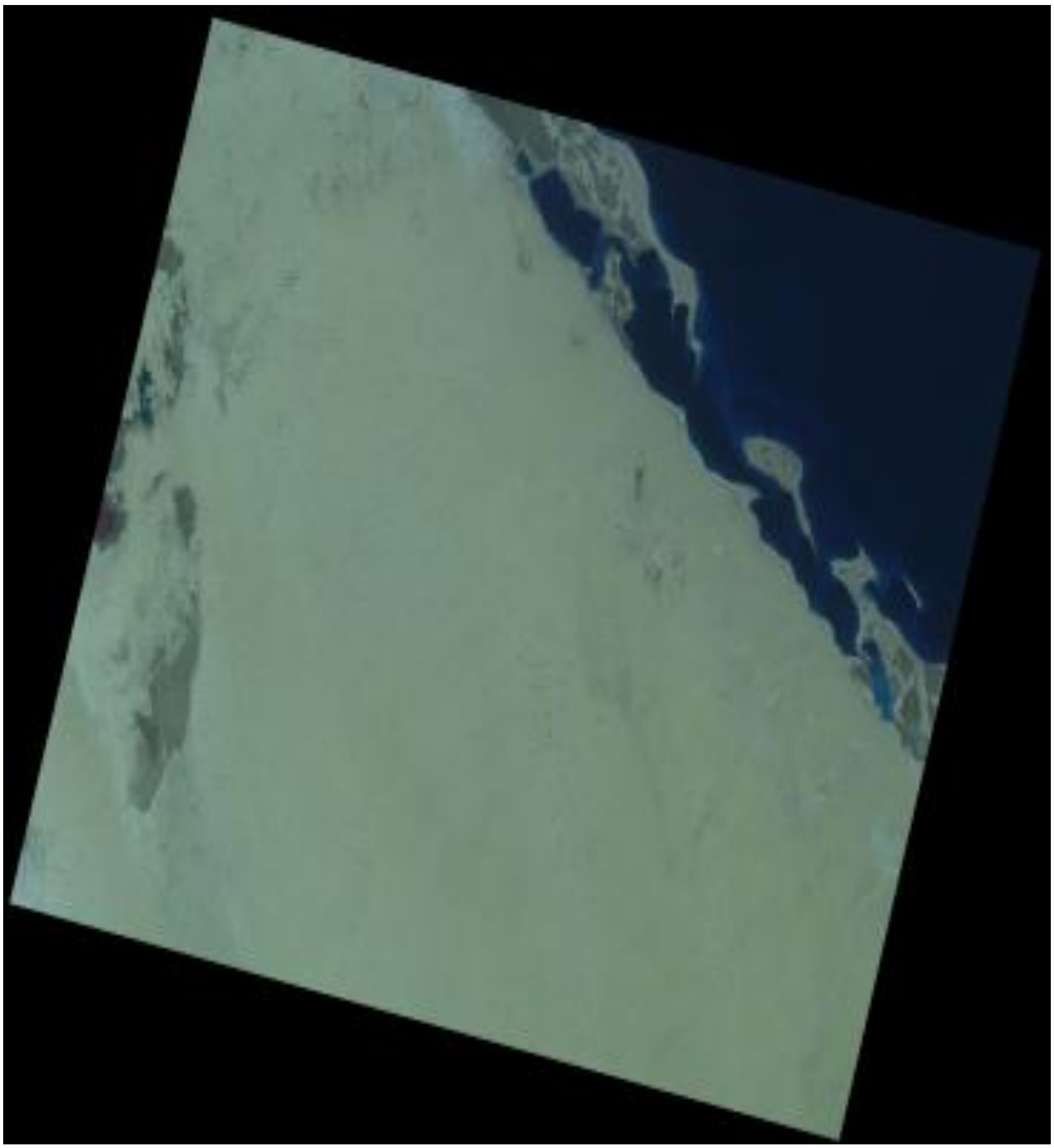
WRSI: Path 153- Row 297

2007



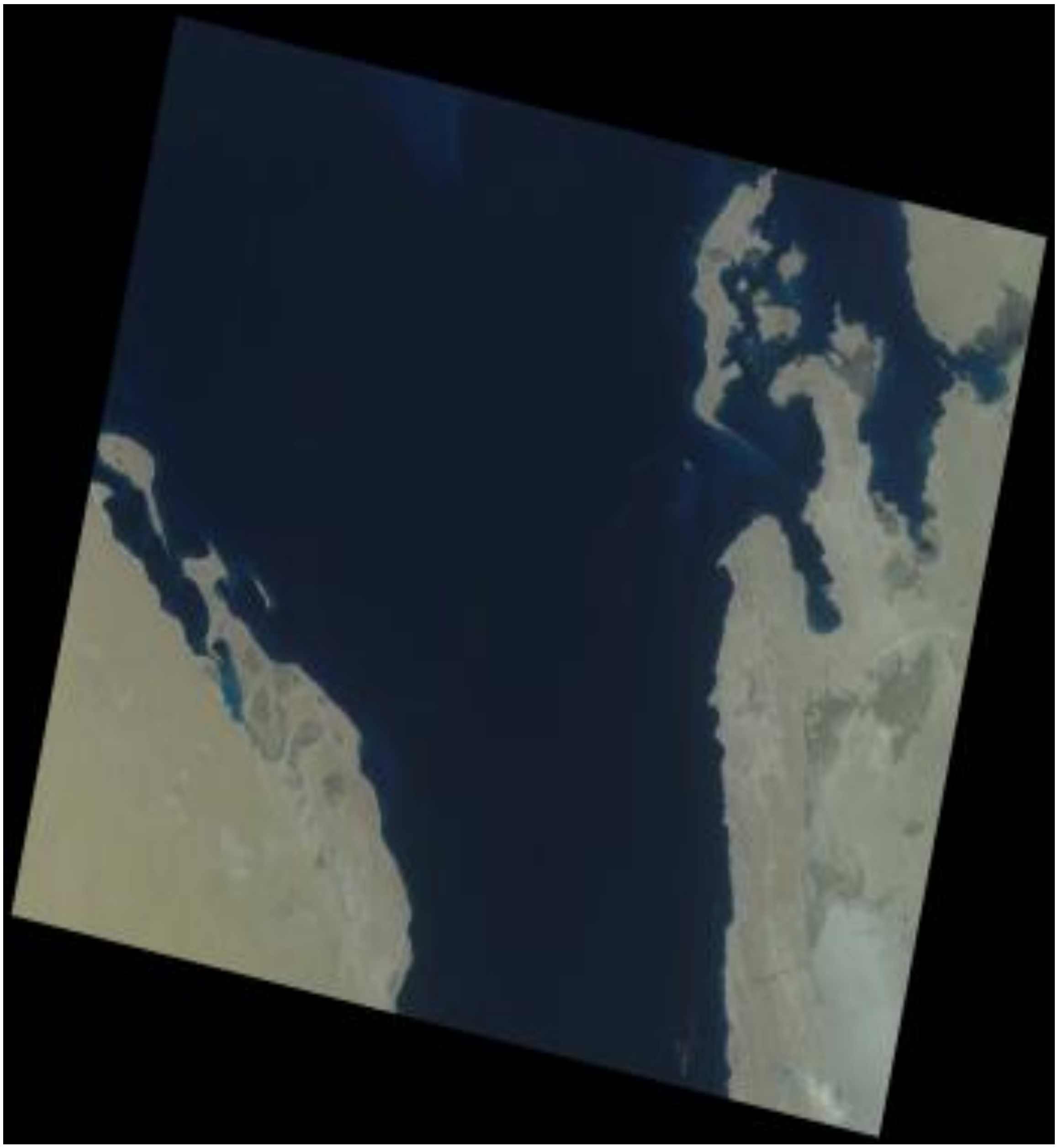
WRSI: Path 153- Row 298

2007



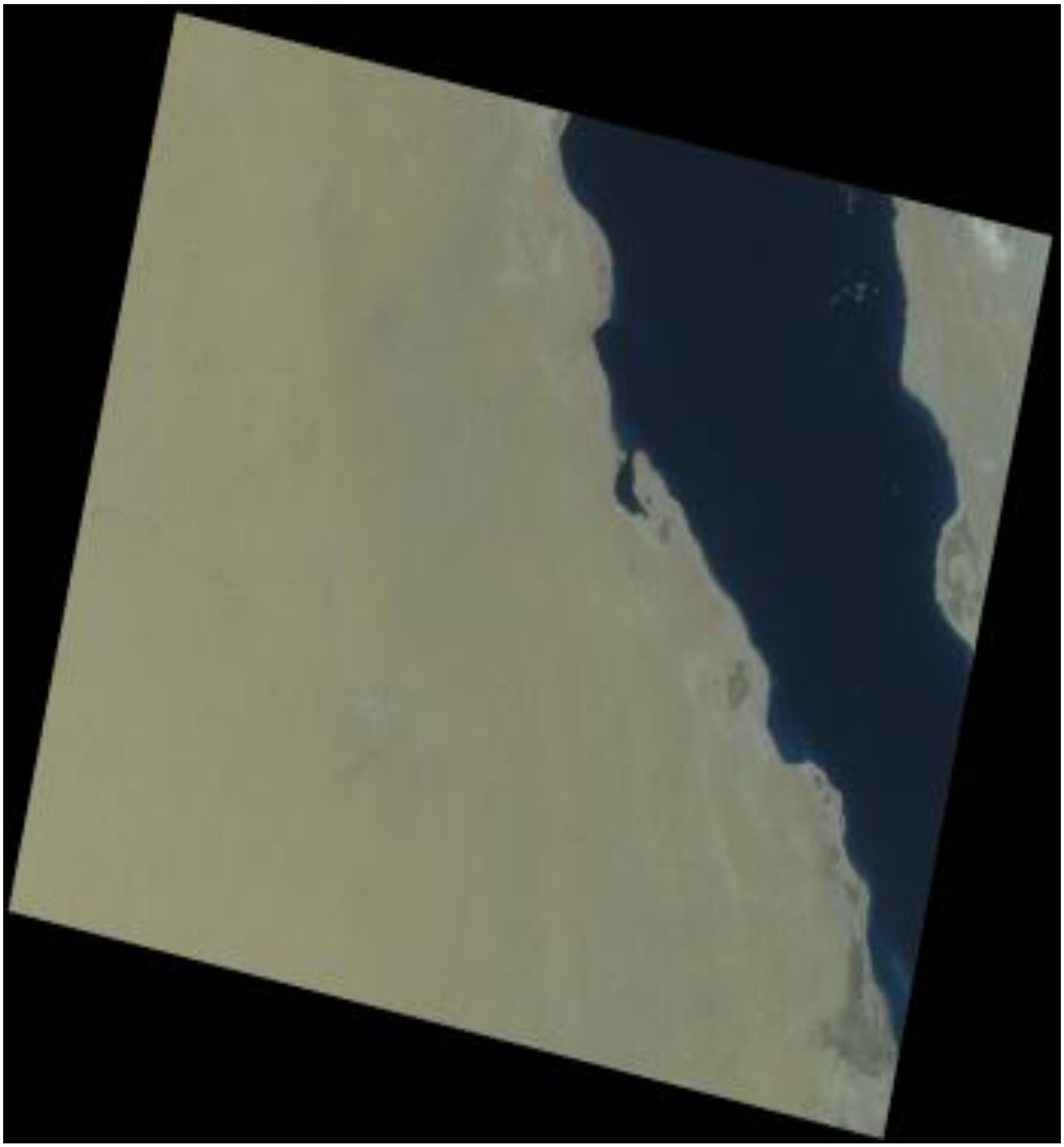
WRSI: Path 153- Row 299

2007



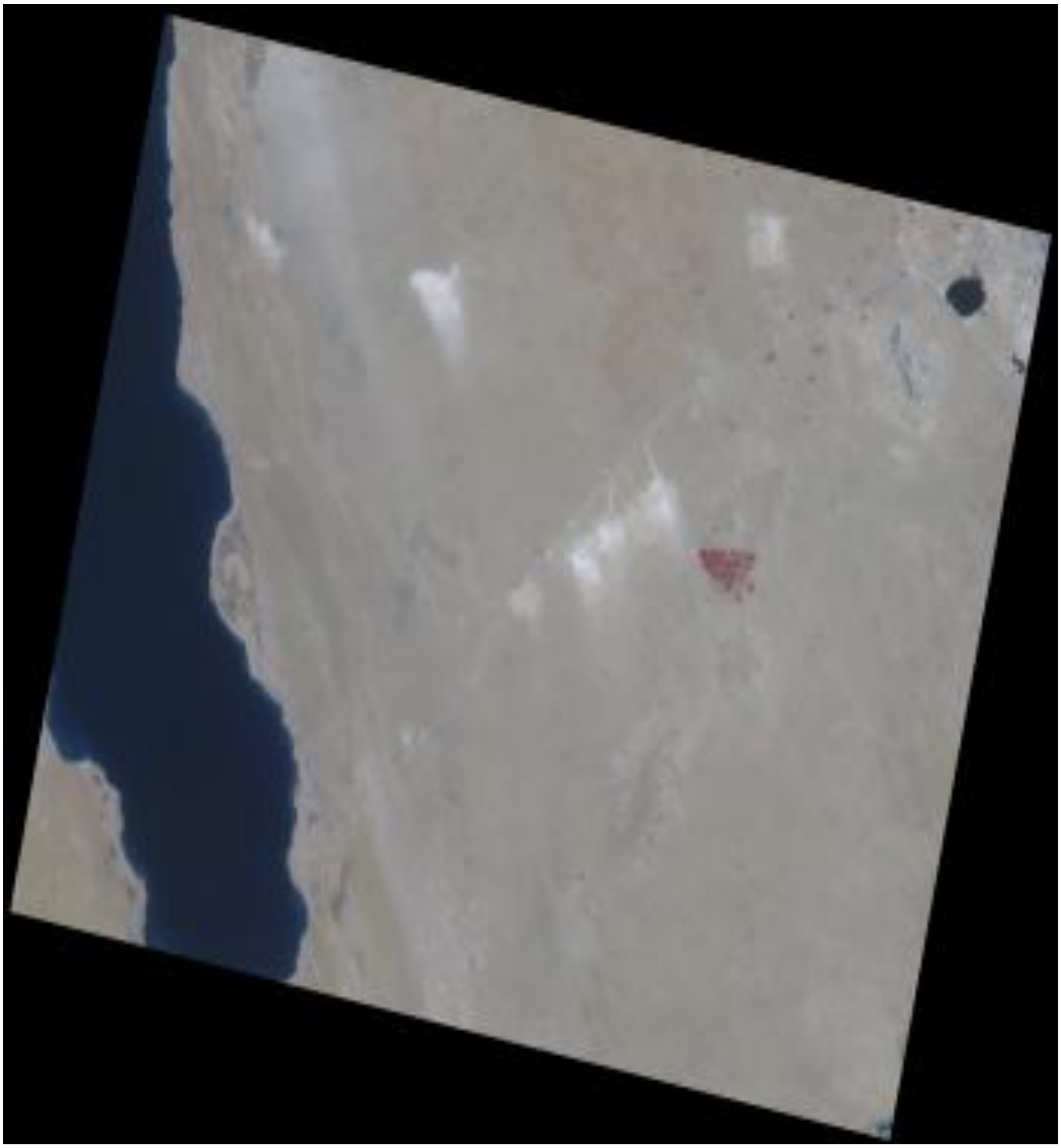
WRSI: Path 154- Row 299

2007



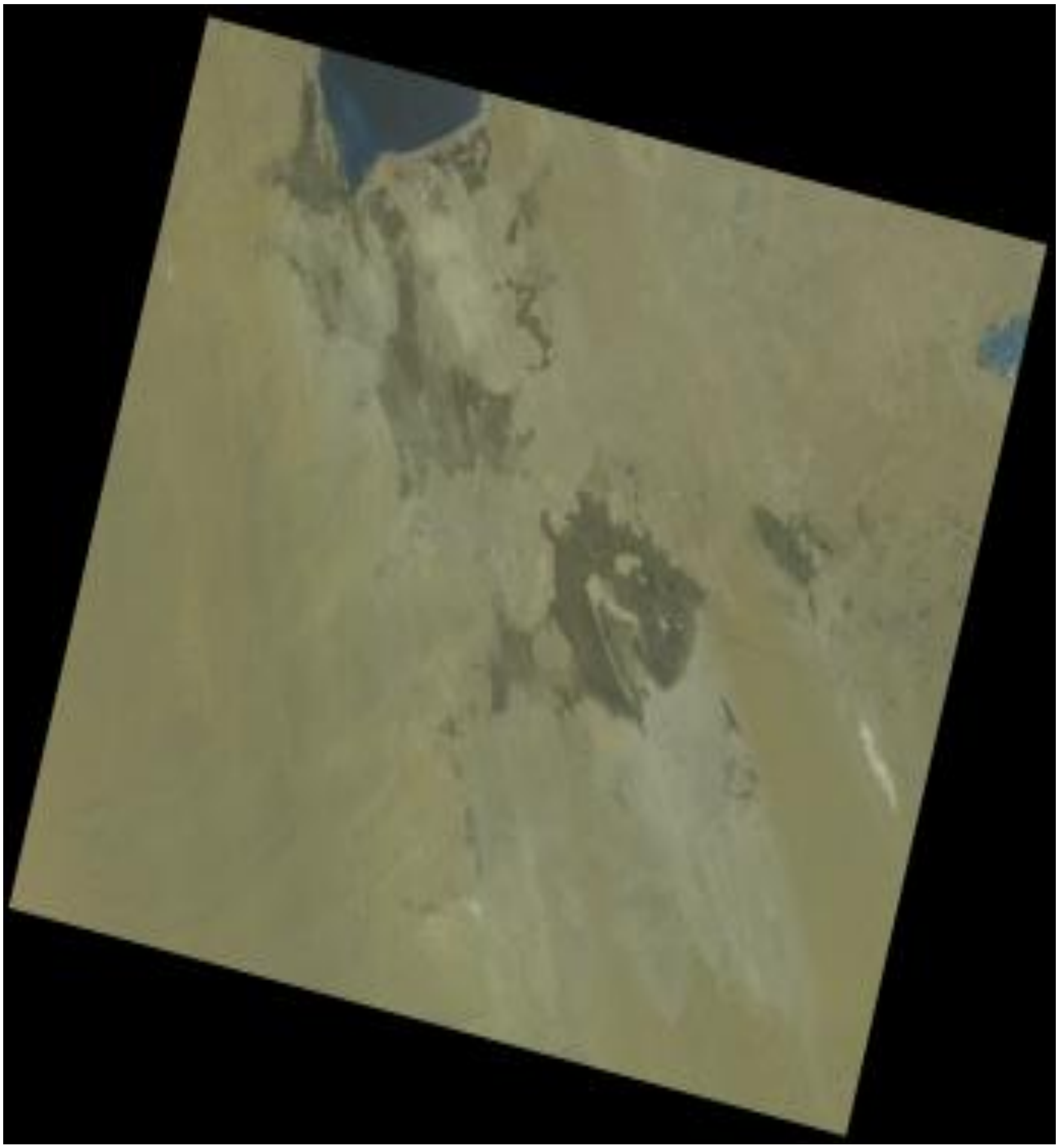
WRSI: Path 154- Row 300

2007



WRSI: Path 155- Row 300

2007



WRSI: Path 155- Row 301

2007

# VITA

Tawfiq received his associated Diploma in industrial Laboratory Operation from AL-Jubail collage (89-92) and his BS in Chemical Science from University of Toledo, Ohio, USA (1994-1997).

Tawfiq Al-Rowaished is Saudi national joined Saudi Aramco in May, 2001 and worked in Southern Area Producing Engineering Department (SAPED) as a lab scientist in Hydrocarbon Analysis Unit. He was responsible to monitor the quality of lube oil used for rotating equipment's companywide under Saudi Aramco corporate program "oil conditioning monitoring" (OCM). Tawfiq started his career as lab technician handling the analysis of ethylene glycol and polyethylene process and product samples in "Sharq" one of Sabic Affiliates from April, 1992 till August, 1994. After earning his bachelor degree in chemical science end of 1997 from the university of Toledo, Ohio (USA), he join Al-Jubail petrochemical company (Kemya), as lab chemist responsible about the quality of polyethylene and ethylene product till May 2001. When join Saudi Aramco in 2001 till the end of 2009, Tawfiq handle the quality of lube oil for companywide rotating equipments under OCM program. And during his assignment with Dhahran research center he assists in technical service projects and crude characterization activities in which he provided technical support for the ongoing oil sales & marketing and refining operations technical issues. Tawfiq currently live in Dammam (Ohod District) and can be contacted by Tele: +966(03)872-2490 or via email: tawfiq.rowaished@aramco.com.