

## ACKNOWLEDGEMENTS

In the beginning, thanks God, who give me the support and the ability to finish this work.

I would like to thank and express my deepest appreciation to my supervisor **Prof. Dr. Hassan Gaber El Ghazouly**, Prof. of Surveying and Geodesy, Faculty of Engineering, Alexandria University, for his support, patience, and continuous gentle prodding.

My immeasurable thanks go to **Prof. Dr. Mohammed Mahmoud Hosny**, Prof. of Surveying and Geodesy, Faculty of Engineering, Alexandria University, for his useful gaudiness, smart ideas and endless support.

I express my gratitude to **Prof. Dr. Hossam Farid El-Hbrouk**, Prof. of Surveying and Geodesy, Faculty of Engineering, Alexandria University, for his continuous support and valuable supervision during the achievement of the research.

I owe a great intellectual debt to all the supervision staff; I would like to express my appreciation for them.

Special thanks to my **family; Parents, Sisters, and Brother.**

My unending gratitude to my friend and husband, **Dr Mohammed Obada**, who encouraged and supported me to finish this research.

Finally, I dedicate this work to my lovely son **Adam Obada.**

| <b>TABLE OF CONTENTS</b>                                       | <b>PAGE</b> |
|--|-------------|
| <b>ABSTRACT</b>  | <b>I</b>    |
| <b>ACKNOWLEDGEMENT</b>   | <b>III</b>  |
| <b>TABLE OF CONTENTS</b>                                       | <b>IV</b>   |
| <b>ABBREVIATIONS</b>   | <b>X</b>    |
| <b>LIST OF FIGURES</b>   | <b>XIII</b> |
| <b>LIST OF TABLES</b>  | <b>XVI</b>  |
| <b>CHAPTER (1): INTRODUCTION</b>                               | <b>1</b>    |
| <b>1.1 STATEMENT OF THE PROBLEM</b>                            | <b>1</b>    |
| <b>1.2 PURPOSE OF STUDY</b>                                    | <b>2</b>    |
| <b>1.3 THESIS OUTLINE</b>                                      | <b>3</b>    |
| <b>CHAPTER (2): LETRTURE REVIEW AND METHODOLOGY</b>            | <b>5</b>    |
| <b>2.1 INTRODUCTION</b>  | <b>5</b>    |
| <b>2.2 OIL EXPLORATION HISTORY</b>                             | <b>5</b>    |
| <b>2.2.1 History of oil exploration using satellite images</b> | <b>7</b>    |
| <b>2.3 REMOTE SENSING REVIEW</b>                               | <b>10</b>   |
| <b>2.3.1 Electromagnetic Energy</b>                            | <b>10</b>   |
| <b>2.3.2 Reflection and Absorption</b>                         | <b>11</b>   |
| <b>2.3.3 Sensors</b>   | <b>12</b>   |
| <b>2.3.4 Satellite Sensor Characteristics</b>                  | <b>12</b>   |
| <b>2.3.4.1 Spatial Resolution</b>                              | <b>13</b>   |
| <b>2.3.4.2 Temporal Resolution</b>                             | <b>13</b>   |
| <b>2.3.4.3 Spectral Resolution</b>                             | <b>13</b>   |
| <b>2.3.5 Common Satellites Used for Oil Exploration</b>        | <b>13</b>   |

|  |    |
|--|----|
| 2.3.5.1 Landsat  | 14 |
| 2.3.5.2 Indian Remote Sensing Satellites (IRS)                     | 16 |
| 2.3.5.3 ASTER  | 18 |
| 2.3.5.4 NOAA   | 20 |
| 2.3.5.5 MODIS  | 21 |
| 2.3.6 Spectral Signatures Of Natural and Human-Made Materials      | 22 |
| 2.3.6.1 Spectral Reflectance Signature                             | 22 |
| 2.3.6.2 Color Composite Images                                     | 23 |
| 2.3.6.2 False Color Composite                                      | 24 |
| 2.3.6.4 Natural Color Composite                                    | 24 |
| 2.3.7 Image Processing and Analysis                                | 25 |
| 2.3.7.1 Digitizing of Images                                       | 26 |
| 2.3.7.2 Image Enhancement  | 26 |
| 2.3.7.3 Image Classification                                       | 26 |
| 2.3.8 Image Interpretation   | 27 |
| 2.3.8.1 Elements of Visual Interpretation                          | 28 |
| 2.4 REMOTE SENSING APPLICATIONS FOR OIL EXPLORATION                | 32 |
| 2.4.1 Formation and Exploration Of Oil                             | 32 |
| 2.5 METHODOLOGY  | 34 |
| 2.5.1 Finding Oil From Space                                       | 34 |
| 2.5.2 Identification of Potential Oil Sites                        | 35 |
| 2.5.2.1 Fracture Systems (Lineaments)                              | 35 |
| 2.5.2.2 Geochemical Alterations of Surficial Rocks by Hydrocarbons | 36 |
| 2.5.2.3 Oil Sands Exposed On Surface                               | 38 |

|   |           |
|---|-----------|
| <b>2.5.3 An Optical Model for the Interpretation of Remotely Sensed Multispectral Images of Oil Detection</b> | <b>40</b> |
| <b>2.5.3.1 Oil Optical Properties</b>   | <b>41</b> |
| <b>2.5.3.2 Optical Model Of Upwelling Radiance</b>  | <b>43</b> |
| <b>2.5.3.3 Upwelling Radiance From Clean Sea Water</b>  | <b>44</b> |
| <b>2.5.3.4 Impact Of Surface Oil Film On Upwelling Radiance Distribution</b>                                  | <b>45</b> |
| <b>2.5.3.5 Definition Of Oil-Water Spectral Contrast</b>  | <b>47</b> |
| <b>2.5.3.6 Description Of The Oil – On – Water Signature Simulator</b>  | <b>48</b> |
| <b>2.6 DOMINANT FACTORS IN USING REMOTE SENSING IMAGES FOR OIL EXPLORATION</b>                                | <b>50</b> |
| <b>2.6.1 Study Area Topography</b>  | <b>51</b> |
| <b>2.6.2 Geological Structure</b>   | <b>51</b> |
| <b>2.6.2.1 Petroleum Geological System</b>  | <b>51</b> |
| <b>2.6.2.2 Source Rock Hydrocarbon Generation</b>   | <b>51</b> |
| <b>A. Migration</b>   | <b>52</b> |
| <b>B. Accumulation</b>  | <b>52</b> |
| <b>C. Reservoir</b>   | <b>52</b> |
| <b>D. Seal (Cap Rock)</b>   | <b>52</b> |
| <b>E. Trap</b>  | <b>53</b> |
| <b>2.6.3 Existing Auxiliary Data</b>  | <b>53</b> |
| <b>2.6.4 Satellite Image</b>  | <b>53</b> |
| <b>2.6.4.1 Selecting Suitable Satellite Images</b>  | <b>54</b> |
| <b>2.6.4.2 Multi Source And Multi Temporal Satellite Images</b>   | <b>56</b> |
| <b>CHAPTER (3) RANKING AND OPTIMUM DATA SELECTION PATH</b>  | <b>58</b> |
| <b>3.1 INTRODUCTION</b>   | <b>58</b> |
| <b>3.2 DATA STUDY FOR SELECTED CASES</b>  | <b>58</b> |

|   |           |
|---|-----------|
| <b>3.2.1 Case 1</b>   | <b>58</b> |
| <b>3.2.2 Case 2</b>   | <b>59</b> |
| <b>3.2.3 Case 3</b>   | <b>60</b> |
| <b>3.2.4 Case 4</b>   | <b>60</b> |
| <b>3.2.5 Case 5</b>   | <b>61</b> |
| <b>3.2.6 Case 6</b>   | <b>62</b> |
| <b>3.2.7 Case 7</b>   | <b>62</b> |
| <b>3.2.8 Case 8</b>   | <b>63</b> |
| <b>3.2.9 Case 9</b>   | <b>64</b> |
| <b>3.2.10 Case 10</b>   | <b>65</b> |
| <b>3.2.11 Case 11</b>   | <b>65</b> |
| <b>3.2.12 Case 12</b>   | <b>66</b> |
| <b>3.2.13 Case 13</b>   | <b>67</b> |
| <b>3.2.14 Case 14</b>   | <b>67</b> |
| <b>3.2.15 Case 15</b>   | <b>68</b> |
| <b>3.2.16 Case 16</b>   | <b>69</b> |
| <b>3.2.17 Case 17</b>   | <b>69</b> |
| <b>3.2.18 Case 18</b>   | <b>70</b> |
| <b>3.2.19 Case 19</b>   | <b>71</b> |
| <b>3.2.20 Case 20</b>   | <b>71</b> |
| <b>3.3 OBJECTS LIBRARY FOR OIL EXISTENCE INDICATORS INTERPRETED ON DIFFERENT SATELLITE IMAGES</b> | <b>72</b> |
| <b>3.3.1 Detection of Oil Indicators In Ocean / Sea Area</b>                                      | <b>72</b> |
| <b>3.3.1.1 Detection of Oil In Various Spectrums</b>  | <b>73</b> |
| <b>3.3.1.1.1 Detection In The Thermal Infrared Region</b>   | <b>73</b> |

|  |            |
|--|------------|
| 3.3.1.1.2 Detection in the Ultraviolet Region                                    | 73         |
| 3.3.1.1.3 Detection in the Visible Region  | 74         |
| 3.3.1.1.4 Oil Spill Detection in the Microwave Region                            | 74         |
| 3.3.2 Offshore Seeps- Detection by SAR Technology                                | 75         |
| 3.3.3 Detection of Oil Indicators In The Offshore River Area                     | 78         |
| 3.3.4 Detection of Oil Indicators In Desert Area                                 | 78         |
| 3. 4 CASES DATA SUMMARY  | 85         |
| 3.5 FACTORS RANKING  | 86         |
| 3.6 RECOMMENDED OPTIMUM PATH FOR FINAL DECISION MAKER                            | 87         |
| 3.6.1 Work flow fine points  | 89         |
| 3.6.2 Summary  | 90         |
| <b>CHAPTER (4): PROPOSAL SYSTEM DESIGN ELEMENTS AND ANTICIPATED SIGNIFICANCE</b> | <b>91</b>  |
| 4.1 INTRODUCTION   | 91         |
| 4.2 PART 1: SMART OIL EXPLORATION SOFTWARE                                       | 91         |
| 4.2.1 Smart Oil Exploration Software Description                                 | 91         |
| 4.2.2 Interface Tools  | 92         |
| 4.2.3 Project Analysis and Ranking Using Smart Oil Exploration                   | 96         |
| 4.2.4 Summary  | 99         |
| 4.3 PART 2: QUESTIONNAIRE  | 99         |
| 4.3.1 Link And Collaboration Between Research And Oil Exploration Industry       | 99         |
| 4.3.1 Questioner And Oil Industry Member's Feedback                              | 99         |
| 4.3.3 Summary  | 105        |
| <b>CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS</b>                                | <b>107</b> |
| 5.1 CONCLUSIONS  | 107        |

|                            |            |
|----------------------------|------------|
| <b>5.2 RECOMMENDATIONS</b> | <b>108</b> |
| <b>REFERENCES</b>          | <b>110</b> |
| <b>APPENDIX A</b>          | <b>117</b> |
| <b>APPENDIX B</b>          | <b>123</b> |
| <b>ARABIC SUMMARY</b>      |            |

## ABBREVIATIONS

|               |   |
|---------------|---|
| <b>MDC:</b>   | <b>Minimum Distance to Class</b>                                      |
| <b>ARIH:</b>  | <b>Advanced Resources International Houston</b>                       |
| <b>ASTER:</b> | <b>Advanced Spaceborne Thermal Emission and Reflection Radiometer</b> |
| <b>AVG:</b>   | <b>Average</b>  |
| <b>BP:</b>    | <b>British petroleum</b>  |
| <b>DEM:</b>   | <b>Digital Elevation Models</b>                                       |
| <b>DN:</b>    | <b>Digital Number</b>   |
| <b>DTM:</b>   | <b>Digital Terrain Models</b>   |
| <b>ED:</b>    | <b>European Datum</b>   |
| <b>EM :</b>   | <b>Electromagnetic Spectrum</b>                                       |
| <b>ETM :</b>  | <b>Enhanced Thematic Mapper</b>                                       |
| <b>FCC:</b>   | <b>False Color Composite</b>  |
| <b>FOV:</b>   | <b>Field Of View</b>  |
| <b>FSP:</b>   | <b>Feature Selection Program</b>                                      |
| <b>GCP's:</b> | <b>ground control points</b>  |
| <b>GOSD:</b>  | <b>Global Offshore Seeps Database</b>                                 |

|                        |   |
|------------------------|---|
| <b>GPS:</b>            | <b>Global Positioning System</b>              |
| <b>ha:</b>             | <b>Hectare</b>                                |
| <b>HC:</b>             | <b>Hydrocarbon</b>                            |
| <b>IFOV:</b>           | <b>Instantaneous Field Of View</b>            |
| <b>Landsat<br/>TM:</b> | <b>Landsat Thematic Mapper</b>                |
| <b>NDVI:</b>           | <b>Normalized Difference Vegetation Index</b> |
| <b>NIR:</b>            | <b>Near Infra Red</b>                         |
| <b>NPA</b>             | <b>: National Petroleum Authority</b>         |
| <b>PC:</b>             | <b>Principal Component</b>                    |
| <b>PCA:</b>            | <b>Principle Component Analyses</b>           |
| <b>SAM :</b>           | <b>Spectral Angle Mapper</b>                  |
| <b>SAR :</b>           | <b>Synthetic Aperture Radar</b>               |
| <b>SD:</b>             | <b>Standard Deviation</b>                     |
| <b>SWIR:</b>           | <b>Short Wave Infra Red</b>                   |
| <b>TIR:</b>            | <b>Thermal Infra Red</b>                      |
| <b>UAE:</b>            | <b>United Arab Emirates</b>                   |
| <b>USGS:</b>           | <b>United States Geological Survey</b>        |

**USTC :**      **Universal Short Title Catalogue**

**UTM:**        **Universal Transverse Mercator**

**VNIR:**       **Visible Near Infra Red**

**WGS:**        **World Geodetic System**

## LIST OF FIGURES

| FIGURE   | PAGE |
|--|------|
| Figure 2.1: Electromagnetic (EM) spectrum range      | 11   |
| Figure 2.2: Active and Passive sensors               | 12   |
| Figure 2.3: Satellite interaction with earth targets | 22   |
| Figure 2.4: Spectral reflectance of objects          | 23   |
| Figure 2.5: Color Composite Images                   | 23   |
| Figure 2.6: Natural Color Composite                  | 25   |
| Figure 2.7: pixel values                             | 26   |
| Figure 2.8: Image Interpretation                     | 27   |
| Figure 2.9: Identification of targets                | 27   |
| Figure 2.10: Tone                                    | 28   |
| Figure 2.11: Shape                                   | 29   |
| Figure 2.12: Size                                    | 29   |
| Figure 2.13: pattern                                 | 30   |
| Figure 2.14: Texture                                 | 30   |
| Figure 2.15: Shadow                                  | 31   |

|                                   |   |           |
|-----------------------------------|---|-----------|
| <b>Figure 2.16:</b>               | <b>Association</b>  | <b>31</b> |
| <b>Figure 2.17:</b>               | <b>Oil Formation and extraction</b>   | <b>33</b> |
| <b>Figure 2.18:</b>               | <b>oil system rock types</b>  | <b>36</b> |
| <b>Figure 2.19</b><br><b>(a):</b> | <b>A three-wavelength method used to detect hydrocarbons of various sizes to determine areas of thick spilled oil.</b>                    | <b>37</b> |
| <b>Figure 2.19</b><br><b>(b):</b> | <b>Hydrocarbon detection</b>  | <b>37</b> |
| <b>Figure 2.20:</b>               | <b>Seep Enhancement Algorithm</b>   | <b>38</b> |
| <b>Figure 2.21:</b>               | <b>Oil slicks as rendered in a natural color Landsat image</b>  | <b>38</b> |
| <b>Figure 2.22:</b>               | <b>The Canadian oil sands</b>   | <b>39</b> |
| <b>Figure 2.23:</b>               | <b>surface stripping of the oil sands</b>   | <b>40</b> |
| <b>Figure. 2.24:</b>              | <b>Absorption coefficients of the four different oils analyzed: diesel, Forties, Alaskan, and Heavy Fuel Oil (HFO)</b>                    | <b>42</b> |
| <b>Figure 2.25:</b>               | <b>Schematization of the upwelling radiance contributions measured by a sensor above a flat sea surface for a clean sea water surface</b> | <b>44</b> |
| <b>Figure 2.26:</b>               | <b>Schematization of oil-on-water signature and oil-water contrast simulator</b>  | <b>49</b> |
| <b>Figure 3.1</b><br><b>(a):</b>  | <b>Surfacing oil pancakes (gas bubbles burst and lost to atmosphere)</b>  | <b>73</b> |
| <b>Figure 3.1</b><br><b>(b) :</b> | <b>Coalescing oil pancakes forming large oil seepage slick (aerial view)</b>  | <b>73</b> |
| <b>Figure 3.2 :</b>               | <b>Seepage Slicks repeating in time in Gulf of Mexico</b>   | <b>75</b> |
| <b>Figure 3.3 :</b>               | <b>Seepage slicks ranking</b>   | <b>77</b> |

|                     |   |           |
|---------------------|---|-----------|
|                     | <b>Examples of seepage slicks identified on RADARSAT-1</b>                              |           |
| <b>Figure 3.4:</b>  | <b>SCN1 and W1 images and corresponding USTC classification results</b>                 | <b>78</b> |
| <b>Figure 3.5:</b>  | <b>Detecting small- and medium-scale impacts. With Quickbird-2 panchromatic imagery</b> | <b>79</b> |
| <b>Figure 3.6:</b>  | <b>Small- and medium-scale impacts.</b>   | <b>80</b> |
| <b>Figure 3.7:</b>  | <b>Direct detection of hydrocarbon seeps using radar imagery.</b>                       | <b>80</b> |
| <b>Figure 3.8:</b>  | <b>Possible seepage slicks identified offshore Indonesia</b>                            | <b>81</b> |
| <b>Figure 3.9:</b>  | <b>Extraction of Hydrocarbon Seeps</b>  | <b>81</b> |
| <b>Figure 3.10:</b> | <b>Enhanced Landsat image of the Baba Dome portion of the Kirkuk oil field</b>          | <b>83</b> |
| <b>Figure 3.11:</b> | <b>Stereo satellite elevation image</b>   | <b>84</b> |
| <b>Figure 3.12:</b> | <b>Slope direction image of a 200km<sup>2</sup> area in western Libya..</b>             | <b>84</b> |
| <b>Figure 3.13:</b> | <b>WorldView 2 satellite ortho photo</b>  | <b>85</b> |

## LIST OF TABLES

| <b>TABLE</b>  | <b>PAGE</b> |
|---|-------------|
| <b>Table 2.1: Landsat Series properties</b>                                       | <b>14</b>   |
| <b>Table 2.2: Landsat Sensors</b>   | <b>15</b>   |
| <b>Table 2.3: TM and ETM+ band designations</b>                                   | <b>16</b>   |
| <b>Table 2.4: IRS Satellites Characteristics</b>                                  | <b>17</b>   |
| <b>Table 2.5: IRS Satellites Sensors</b>  | <b>18</b>   |
| <b>Table 2.6: ASTER Satellites Characteristics</b>                                | <b>19</b>   |
| <b>Table 2.7: NOAA Satellites Characteristics</b>                                 | <b>20</b>   |
| <b>Table 2.8: Advanced Very High Resolution Radiometer</b>                        | <b>20</b>   |
| <b>Table 2.9: MODIS Satellites Characteristics</b>                                | <b>21</b>   |
| <b>Table 2.10: Refractive indexes of the four different oils analyzed</b>         | <b>42</b>   |
| <b>Table 2.11: Satellite sensors and their radiometric and spatial resolution</b> | <b>56</b>   |
| <b>Table 3.1: Case 1 data summary</b>   | <b>59</b>   |
| <b>Table 3.2: Case 2 data summary</b>   | <b>60</b>   |
| <b>Table 3.3: Case 3 data summary</b>   | <b>60</b>   |
| <b>Table 3.4: Case 4 data summary</b>   | <b>61</b>   |

|                    |                               |           |
|--------------------|-------------------------------|-----------|
| <b>Table 3.5:</b>  | <b>Case 5 data summary</b>    | <b>61</b> |
| <b>Table 3.6:</b>  | <b>Case 6 data summary</b>    | <b>62</b> |
| <b>Table 3.7:</b>  | <b>Case 7 data summary</b>    | <b>63</b> |
| <b>Table 3.8:</b>  | <b>Case 8 data summary</b>    | <b>64</b> |
| <b>Table 3.9:</b>  | <b>Case 9 data summary</b>    | <b>64</b> |
| <b>Table 3.10:</b> | <b>Case 10 data summary</b>   | <b>65</b> |
| <b>Table 3.11:</b> | <b>Case 11 data summary</b>   | <b>66</b> |
| <b>Table 3.12:</b> | <b>Case 12 data summary</b>   | <b>66</b> |
| <b>Table 3.13:</b> | <b>Case 13 data summary</b>   | <b>67</b> |
| <b>Table 3.14:</b> | <b>Case 14 data summary</b>   | <b>68</b> |
| <b>Table 3.15:</b> | <b>Case 15 data summary</b>   | <b>68</b> |
| <b>Table 3.16</b>  | <b>: Case 16 data summary</b> | <b>69</b> |
| <b>Table 3.17:</b> | <b>Case 17 data summary</b>   | <b>70</b> |
| <b>Table 3.18:</b> | <b>Case 18 data summary</b>   | <b>70</b> |
| <b>Table 3.19:</b> | <b>Case 19 data summary</b>   | <b>71</b> |
| <b>Table 3.20:</b> | <b>Case 20 data summary</b>   | <b>72</b> |
| <b>Table 3.21:</b> | <b>Cases data summery</b>     | <b>85</b> |

o b e i k e n d i . c o m