A Remote Sensing Study of Some Impacts of Global Warming on the Arab Region

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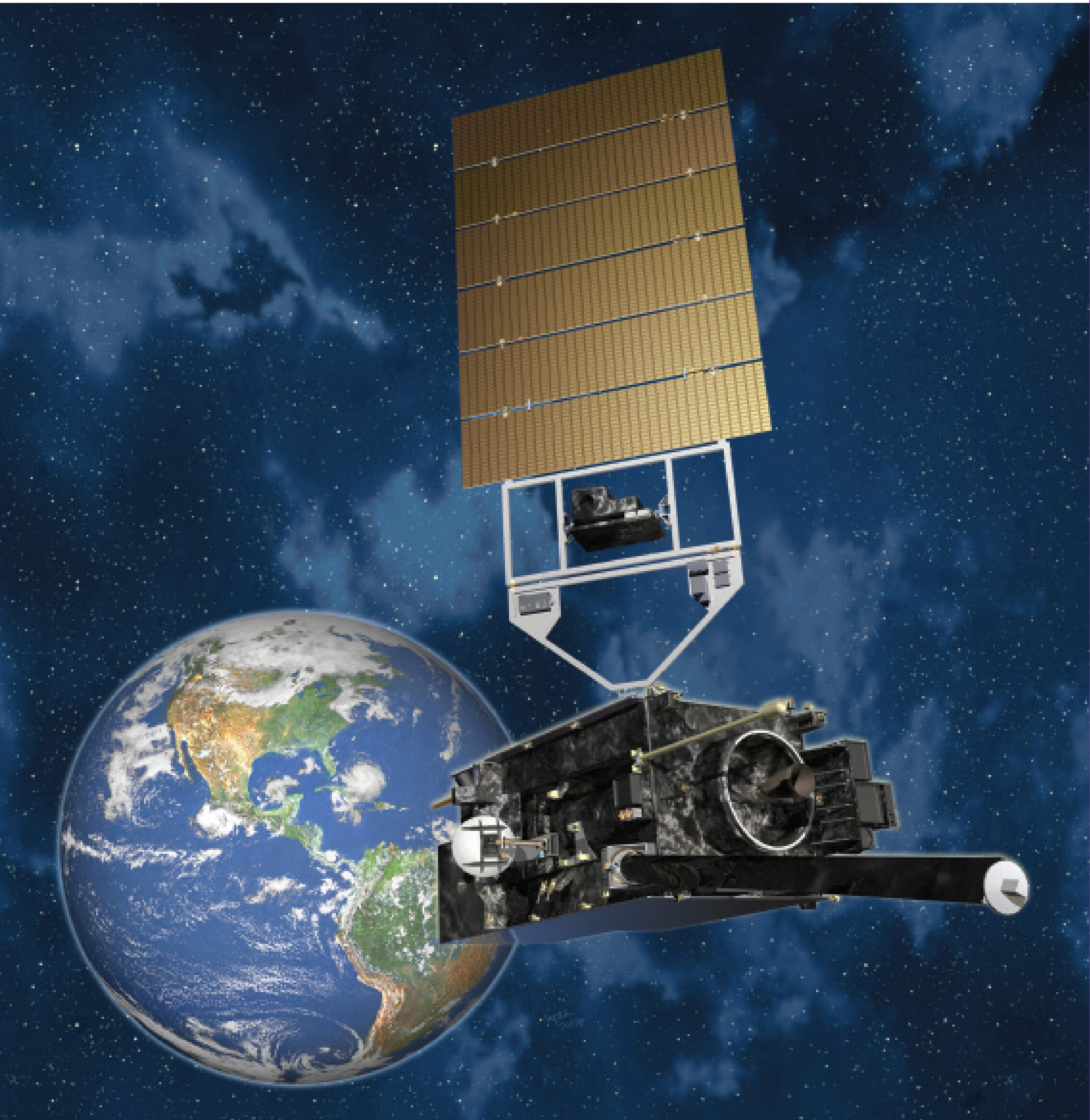
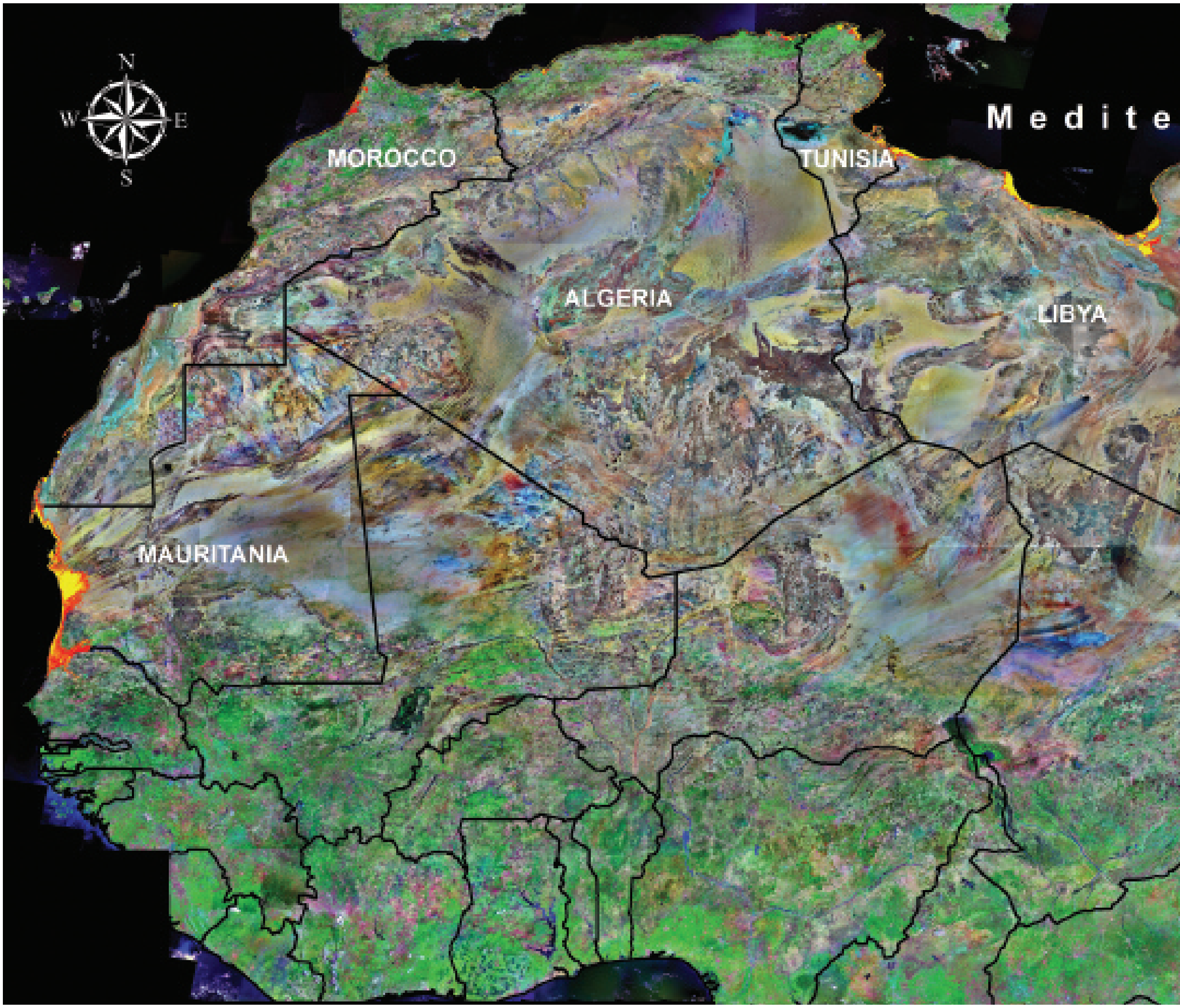


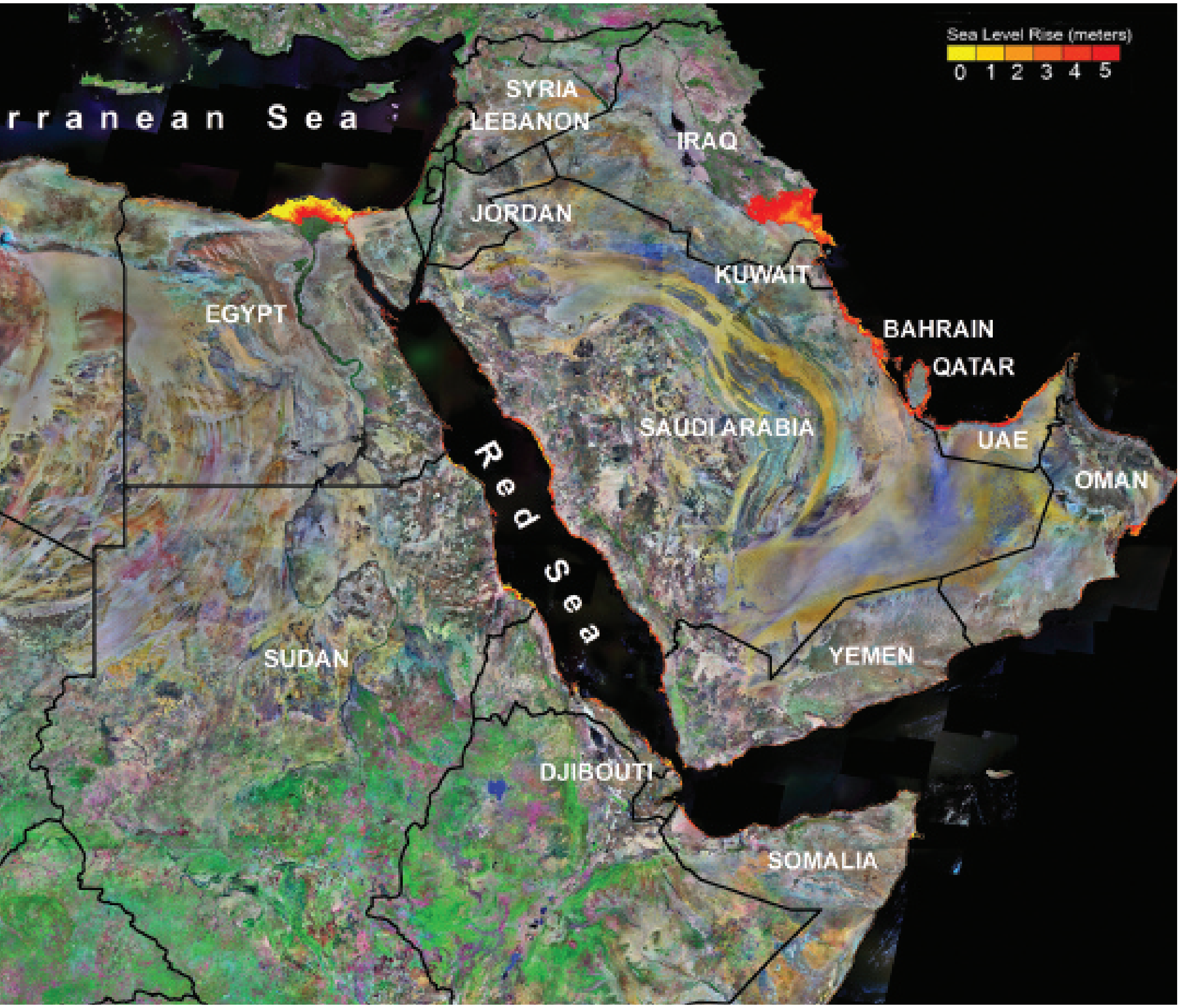
FIGURE 1 SIMULATION OF SEA LEVEL RISE SCENARIOS AT DIFFERENT LEVELS



I. INTRODUCTION

Global warming is one of the most serious challenges facing us today. Under the projected climate changes, many parts of the planet will become warmer. Droughts, floods and other forms of extreme weather will become more frequent, threatening food supplies, economic assets, and human lives. Plants and animals which cannot adapt to the changed weather conditions will die. Sea levels are also rising and will continue to do so, forcing millions of people in coastal zones to migrate inland.

This study uses remote sensing techniques to depict the consequences on the Arab world of various climate change impact scenarios, ranging from conservative to extreme. It neither attempts to endorse a specific level of impact, a matter discussed in other chapters of the report, nor attempts



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to be inclusive of all impacts of climate change which can be traced using remote sensing.

In light of the uncertainty surrounding the exact dynamics of climate change and scientific projections, this study takes into account the range from 1 m to 5 m SLR, without ascribing particular likelihoods to any particular value within that range; as such, the study seeks more to illuminate the potential disastrous ramifications of SLR, whatever the exact SLR will be.

II. IMPACT OF SEA LEVEL RISE ON THE ARAB COUNTRIES

The past century has witnessed a 17 cm rise in the sea level (IPCC, 2001) at a mean rate of 1.75 mm per year (Miller and Douglas, 2004). The IPCC's Fourth Assessment Report published in

FIGURE 2 **SEA LEVEL RISE SCENARIO AT 1 METER**

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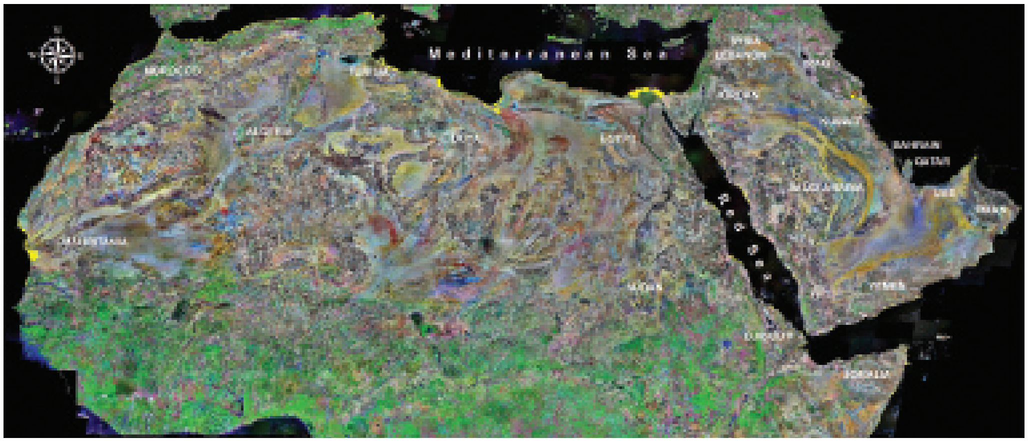
FIGURE 3 **SEA LEVEL RISE SCENARIO AT 2 METERS**



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2007 predicted sea-level rise of up to 59 cm by 2100, excluding effects of potential dynamic changes in ice flow (IPCC, 2007). Taking into account the full "likely" range of predicted increases in temperature, SLR could even be amplified to up to 1.4 m by the year 2100 (Rahmstorf, 2007). Other researchers have predicted between 5-6 meters SLR in the event of the West Antarctic Ice Sheet collapse (Tol et al., 2006). As an indication of recent upward revision of projected climate change scenarios, Christopher Field, an American member of the IPCC and founding director of the Carnegie Institution's Department of Global Ecology at Stanford University, said at the annual meeting of the American Association for the Advancement of Science in February 2009 that the pace of climate change exceeds predictions, as emissions since 2000 have outpaced the estimates used in IPCC 2007 report.

Without any doubt, SLR is a global threat. With varying predictions on the extent of SLR, based on different variables which cannot all be foreseen, there is a near consensus on the need to apply precautionary principles to global warming. This explains why studies of impact, mainly those carried out by the World Bank, consider SLR scenarios between 1-5 meters. The threat emerges from the fact that a large percentage of the earth's population inhabits vulnerable coastal zones. About 400 million people live within 20 km of a coast, worldwide (Gornitz, V., 2000). Worryingly, if the sea level rises by only 1 m, it

FIGURE 4 **SEA LEVEL RISE SCENARIO AT 3 METERS**

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FIGURE 5 **SEA LEVEL RISE SCENARIO AT 4 METERS**

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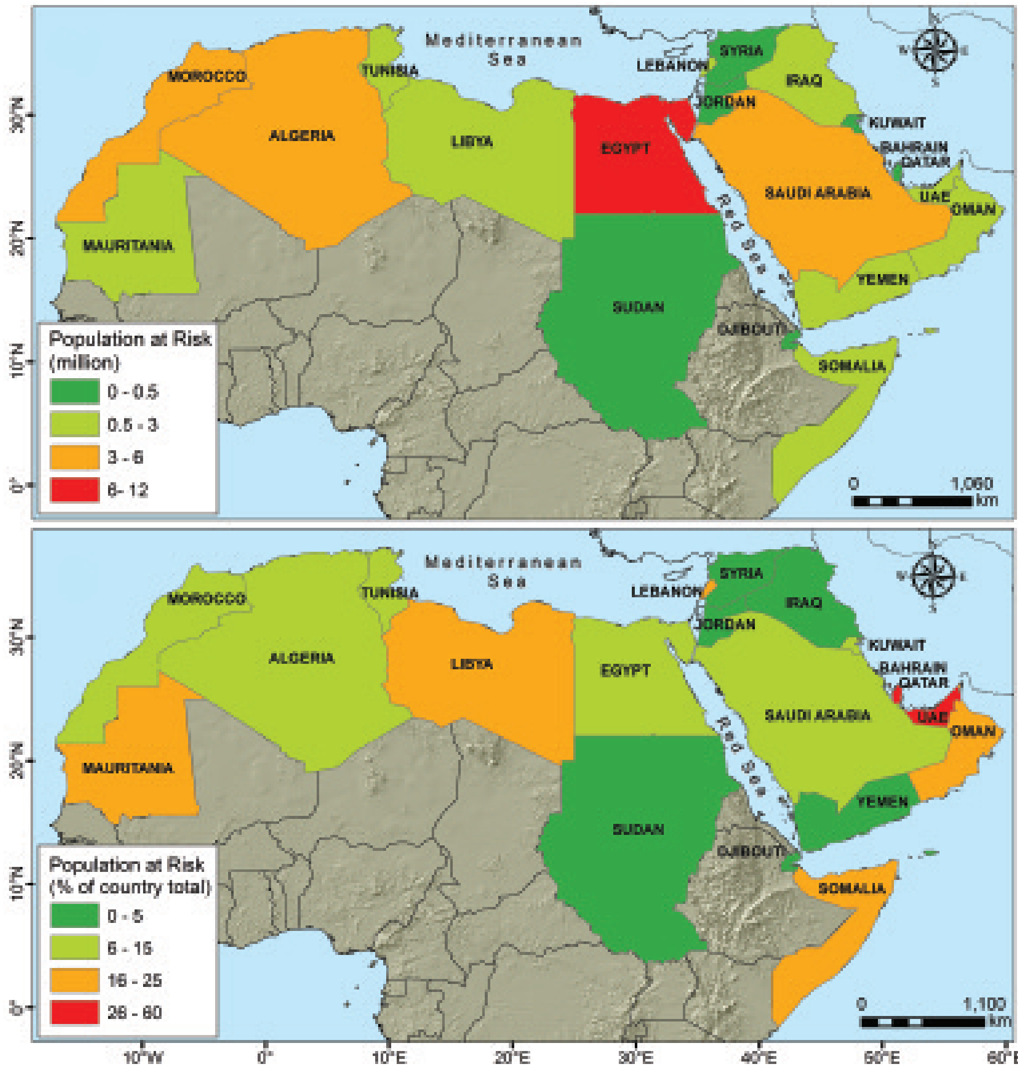
would affect more than 100 million individuals (Douglas and Peltier, 2002). "The melting or collapse of ice sheets would eventually threaten land which today is home to 1 in every 20 people" (Stern, 2006).

The coastal zone of the Arab world is no exception to the threat of SLR. Similar to many parts of the world, capital cities and major towns of Arab countries lie along the coast or on estuaries. Their expansions are extremely rapid and, therefore, these metropolises are at great risk of SLR.

To view more closely the effect of SLR on the Arabian coastline and highlight those countries with high potential risk of SLR, a simulation for SLR has been conducted using the Geographical Information System (GIS) and the Shuttle Radar Topography Mission (SRTM) data. These data, which are widely used in many scientific investigations, are considered to comprise the best Digital Elevation Model (DEM) on a global scale with consistency and overall accuracy (Suna et al., 2003; Ghoneim and El-Baz, 2007, Ghoneim et al., 2007). Figures 1 to 5 show results of this simulation.

Under the 1 m SLR scenario, the simulation reveals that approximately 41,500 km^2 of the territory of the Arab countries would be directly impacted by the rise of the sea level. Projected increases in sea levels will displace a quickly growing population into more concentrated areas. At least 37 million people (~11%) will be

FIGURE 6 **POPULATION AT RISK AT EXTREME 5 METERS SEA LEVEL RISE**



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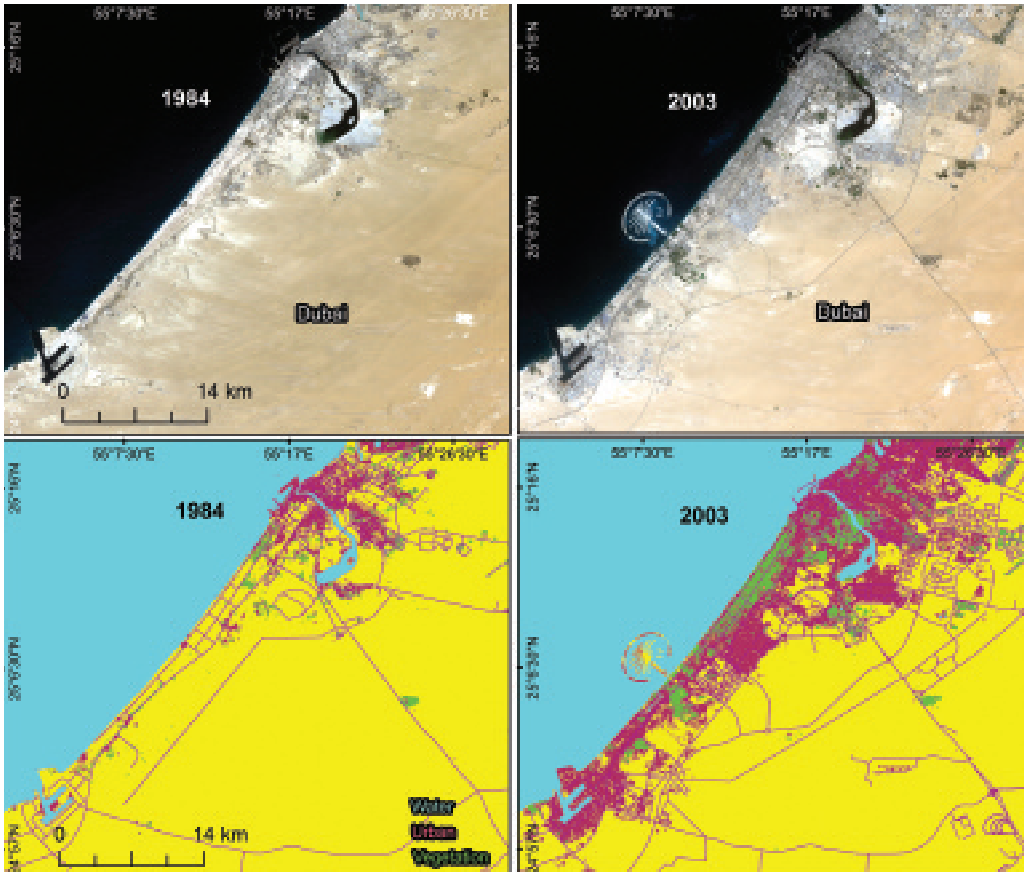
directly affected by SLR of 1 meter. In the case of 2, 3 and 4 m SLR scenarios, around 60,000, 80,700 and 100,800 km^2, respectively, of the Arab coastal region will be seriously impacted. In the extreme case of 5 m SLR, such impact will be at its highest, as it is estimated that up to 113,000 km^2 (0.8%) of the coastal territory would be inundated by sea water (Figure 1-5).

Potential impacts of SLR, however, are not uniformly distributed across the Arab region. From Figure 6a it is obvious that the SLR impact will be particularly severe in some countries such as Egypt, Saudi Arabia, Algeria and Morocco, whereas it will have a lesser impact on others such as Sudan, Syria, and Jordan. Egypt will be by far the most impacted country of the Arab world; at least 12 million Egyptians will be displaced with the 5 m SLR scenario. In fact, approximately one third of the Arab population impacted will be from Egypt alone. At the nation level, the United Arab Emirates (UAE), Qatar and Bahrain will witness the highest SLR effect in terms of the percentage of population at risk from the total country population. Here, we project that more than 50% of the population of each country will be impacted by 5m SLR (Figure 6b). The current analysis indicates that Bahrain and Qatar would experience a significant reduction of about 13.4 % and 6.9%, respectively, of their land as a result of the 5 m SLR scenario.

FIGURE 7

BASED ON SATELLITE IMAGE CLASSIFICATION AND CHANGE DETECTION ANALYSIS, IT IS ESTIMATED THAT IN ONE OF THE STUDY SITES IN THE UAE, URBAN GROWTH HAS EXPANDED ALMOST THREE TIMES IN AREA (FROM 78.54 KM^2 TO 226.11 KM^2) DURING THE LAST 20 YEARS (1984 TO 2003). GREEN LANDS OF THE SAME STUDY SITE HAVE ALSO DOUBLED IN THEIR SURFACE AREA (FROM 26.62 KM^2 TO 47.57 KM^2) DURING THE SAME PERIOD.



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III. COASTAL URBANIZATION

There are factors – both human and natural – that might contribute and intensify the impact of the SLR. For example, for most parts of the Arab world, rapid and uncontrolled urbanization is occurring at a large scale along the vulnerable coastal areas. Continuation of such urbanization patterns will draw still greater populations into these low-lying hazardous zones and, consequently, SLR would most likely have a profound impact on the people and on infrastructure development in the coastal areas of the region.

Monitoring historical changes in urbanization can be used to identify future trends in urban expansion independent from climate change, and therefore suggest places that will need to better incorporate climate risks into planning processes. Based on satellite image classification and change detection analysis of the present study (Figure 7), it is estimated, for example, that in Dubai, urban growth (including green areas) has almost tripled its surface area in less than 20 years (between 1984 and 2003). With the addition of the new urbanized area of the Dubai Palm Islands project, the percentage of people and infrastructure likely to be affected by coastal inundation or flooding will be immense.

In order to estimate the total extent of the areas at risk by SLR in more detail, a Digital

FIGURE 8a **DIGITAL ELEVATION MODEL OF THE THREE EMIRATES OF SHARJAH, AJMAN AND UMM AL-QUWAIN WHICH SHOWS THAT A SEA LEVEL RISE OF 1 METER WOULD INUNDATE 1.2% OF SHARJAH, 8.1% OF AJMAN AND 5.9% OF UMM AL-QUWAIN.**

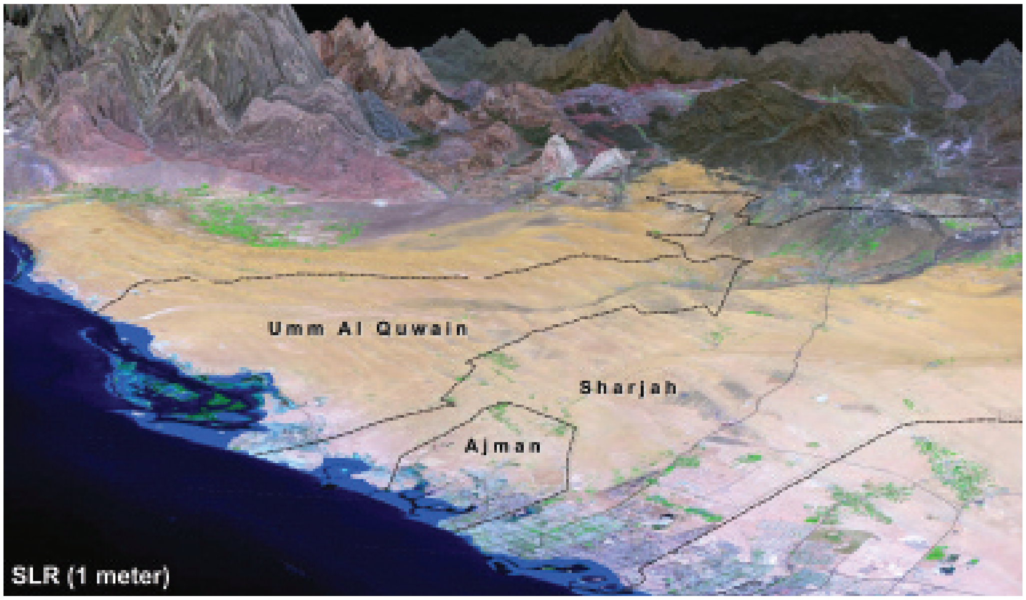

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FIGURE 8b **ZERO METER SLR**

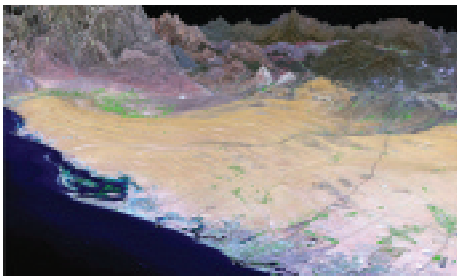
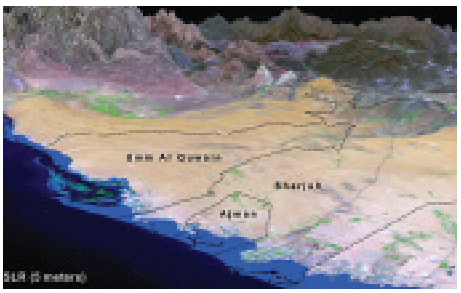


FIGURE 8c **UNDER THE EXTREME CASE OF 5 METER SLR SCENARIO, 3.2% OF SHARJAH, 24% OF AJMAN AND 10% OF UMM AL-QUWAIN LANDS WOULD BE INUNDATED BY SEA WATER.**



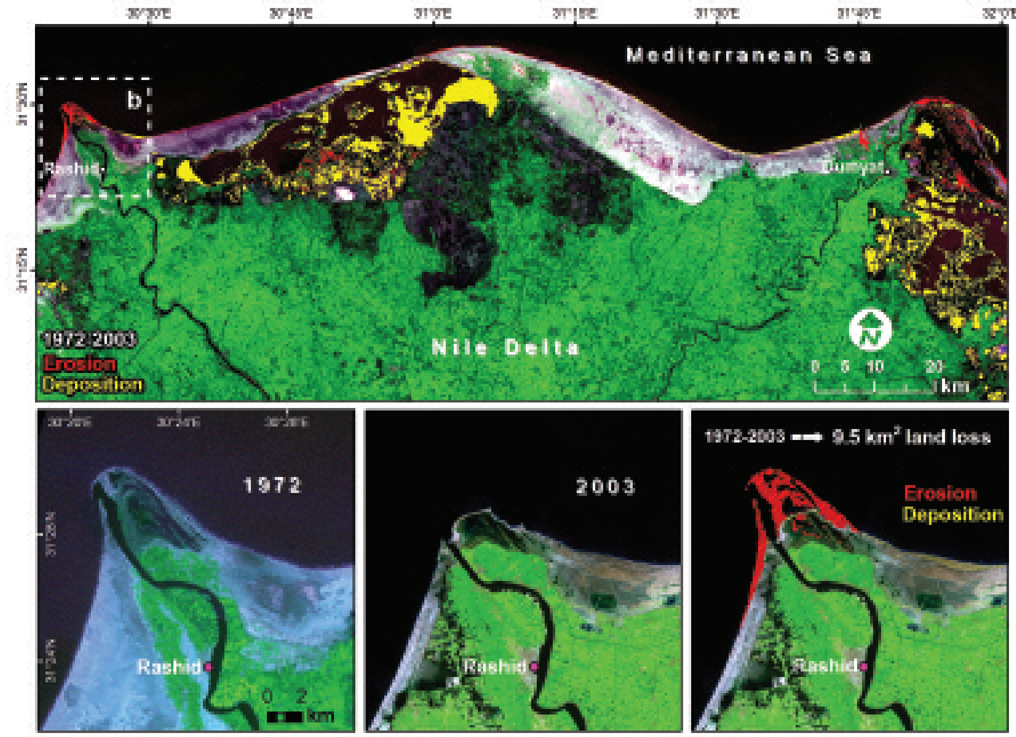
Elevation Model (DEM), for the coastal zone of the three Emirates of Sharjah, Ajman and Umm Al-Quwain, has been constructed from topographic maps. Based on the derived-DEM, it was found that approximately 332 km^2 of the land area of the three Emirates lies below 10 m and is hence highly vulnerable to SLR. Results reveal that a projected SLR of 1 m would inundate approximately 8.1% of the Emirate of Ajman, 1.2% of the Emirate of Sharjah and 5.9% of the Emirate of Umm Al-Quwain (Figure 8b). With the 5 meter scenario, these flooded lands will be increased to reach about 24%, 3.2% and 10% for the three Emirates, respectively (Figure 8c).

IV. IMPACT OF SEA LEVEL RISE ON THE NILE DELTA

In the Arab region, locations that occupy low-lying areas, such as deltaic plains, will face even more serious problems due to SLR. River deltas are particularly vulnerable since increases in sea level are compounded by land subsidence and human interference such as sediment trapping by dams (Church et al., 2008). In the Arab world, the two major deltaic areas are that of the Nile River in Egypt and the Tigris and

FIGURE 9

LANDSAT SATELLITE IMAGES SHOW VAST COASTAL EROSION IN THE NILE DELTA WITH A RETREATING RATE OF UP TO 100 METERS PER YEAR IN SOME AREAS



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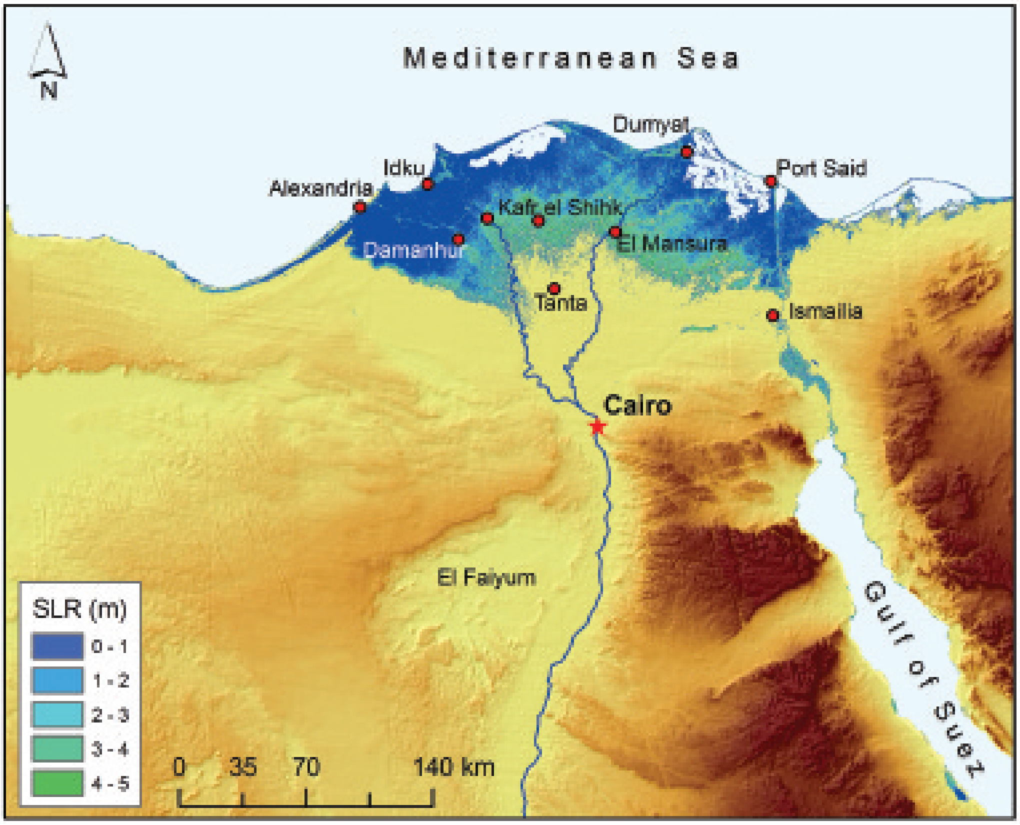
Euphrates in Iraq. These locations are highly populated areas and among the most important agricultural lands in the region. As illustrated from the computed SLR (see Figure 1), these two areas are regionally the most vulnerable. In fact, impacts will be much bigger when combined with increase in the incidence of extreme events on low-level areas.

The total area of Egypt is slightly over one million km?, most of which has an arid and hyper-arid climate. Roughly 94% of Egypt's land mass is made up of desert. The fast growing population, now approaching about 81 million, inhabits less than 6% of the country's land area. This land area, which is located in the Nile Delta and the Nile valley, contains the most productive agricultural land and hence the main food source for the entire country. The Nile Delta, which is about 24,900 km^2 in area, alone accounts for about 65% of Egypt agricultural land. This delta, once the largest depocenter in the Mediterranean, is an extreme example of a flat low-lying area at high risk to SLR (El-Raey, 1997). The delta is presently retreating due to accelerating erosion along the coastline. This has generally been attributed to both human and natural factors. The construction of the Aswan High Dam (1962) and the entrapment of a large amount of sediments behind it, in Lake Nasser, are major factors causing erosion in the Nile Delta. The entrapment of another considerable quantity of Nile sediments by the extremely dense network of irrigation and drainage channels and in the wetland of the northern delta has also contributed greatly to the delta's erosion (Stanley, 1996). At present, only a little amount of the Nile River sediments is carried seaward to replenish the Nile Delta coast at its northern margin. Even the very small remaining amount of the delta sediment presently reaching the Mediterranean is removed by the strong easterly sea currents.

Moreover, the delta's subsidence of about 1 to 5 mm per year (Stanley, 2005), due to both natural causes and heavy groundwater extraction, is influencing the coastal erosion tremendously. Such coastal impact is evident in satellite images, where coastal erosion can be clearly

FIGURE 10 **SLR SCENARIOS OF 1-5 METERS IN THE NILE DELTA REGION**



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seen close to the Rosetta and Damietta promontories (Figure 9). Analysis of Landsat images reveals that the promontory of Rosetta, in particular, has lost approximately 9.5 km^2 in area (Figure 9b) and its coastline has retreated 3 km inland in only 30 years (1972 - 2003). This means that this part of the delta is retreating at an alarming rate of about 100 m per year.

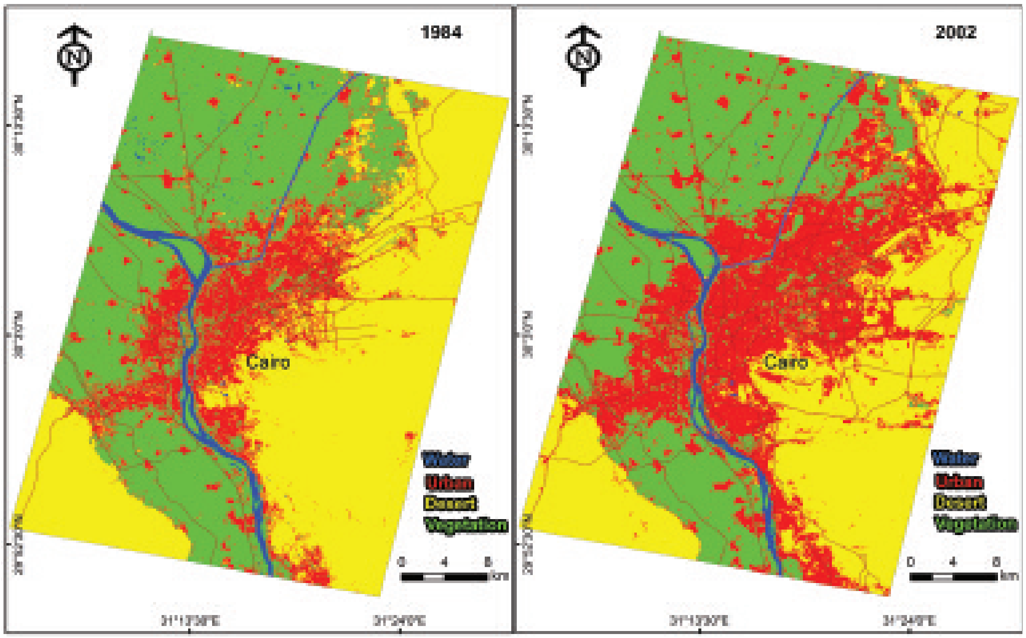
Under SLR scenarios, much more of the Nile Delta will be lost forever. Remote sensing and GIS analysis depict areas of the Nile Delta at risk of 1 m SLR and the extreme case of 5 m SLR (Figure 10). Based on this figure, it is estimated that a sea level rise of only 1 m would flood much of the Nile Delta, inundating about one third (~34%) of its land, placing important coastal cities such as Alexandria, Idku, Damietta and Port-Said at a great risk. In this case, it is estimated that about 8.5 % of the nation's population (~7 million people) will be displaced.

In the extreme case of 5 m SLR, more than half (~58%) of the Nile Delta will be facing destructive impacts, which would threaten at least 10 major cities (among them Alexandria, Damanhur, Kafr-El-Sheikh, Damietta, Mansura and Port-Said), flooding productive agricultural lands, forcing about 14% of the country's population (~11.5 million people) into more concentrated areas to the southern region of the Nile Delta, and thus would contribute to worsening their living standards.

V. IMPACT OF URBANIZATION AND URBAN HEAT ISLAND

The southern part of the Nile Delta is presently suffering from the uncontrolled urbanization of the city of Cairo, the capital city of Egypt. Results of the current investigation show that the total built-up area in Cairo has expanded significantly over the last few decades. The high

FIGURE 11 **CAIRO METROPOLITAN AREA HAS DOUBLED IN LESS THAN 20 YEARS**



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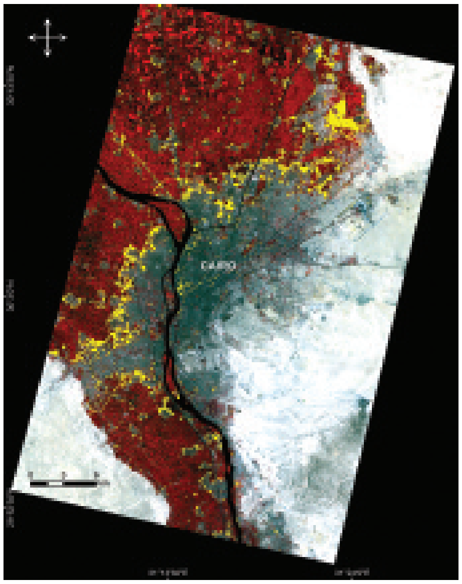
economic growth and employment opportunities in this city caused an influx of labour migration. Local increase of population plus migrants caused the city to expand rapidly and in an uncontrollable fashion. As shown in Figure 11, the Cairo metropolitan area has doubled in size in less than 20 years (1984-2003). Presently, the city has a population of about 17.5 million people, making it the largest and most populous metropolitan area in the Arab world.

As Cairo grows outward, a host of problematic issues are raised. The first of these issues is the loss of prime cultivated lands to urban expansion and development, due to the increase in housing demand. Analysis shows that about 12% (~62 km2) of the farmland areas in the vicinity of Cairo were lost in 18-year time span between 1984 and 2002 (Figure 12). Many large cities of the MENA region (for example Beirut, Figures 14 and 15) show the same disturbing trend of green cover and agricultural land loss for urban expansion. Once these lands have been converted to urban use, green areas and agricultural lands are generally lost forever, cutting down the carbon sinks, and in the long term could cause food scarcity.

FIGURE 12 **12% OF THE FARMLAND AREAS IN THE VICINITY OF CAIRO WERE LOST IN 20 YEARS**



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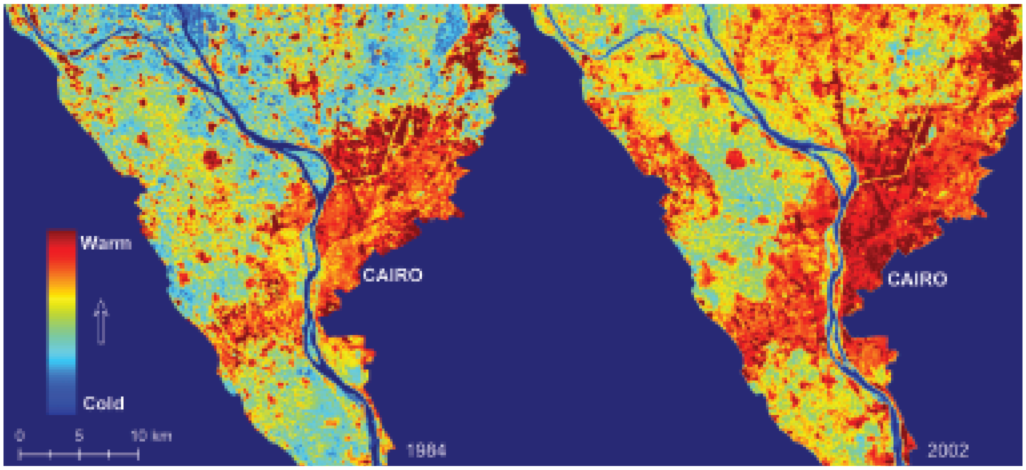
Another problematic issue that relates to urbanization is the Urban Heat Island effect (UHI), for which the temperatures of central urban locations are several degrees higher than those of nearby rural areas of similar elevation.

FIGURE 13 **RAPID URBAN GROWTH IN CAIRO BETWEEN 1984-2002 CAUSED SIGNIFICANT RISE IN SURFACE TEMPERATURE (SHOWN IN RED COLOR), REFERRED TO AS URBAN HEAT ISLAND (UHI) EFFECT**



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Urbanization can have significant effects on local weather and climate (Landsberg, 1981), which in turn can contribute greatly to global warming. Urban expansion usually arises at the expense of vegetation cover when open space is converted to buildings, roads, and other infrastructure. Urban materials used to build these structures do not have the same thermal properties as vegetation cover, and consequently, can largely influence the local urban climate. The urban geometry of a city can increase surface temperatures as well by obstructing air flow and preventing cooling by convection.

Studies on surface temperature characteristics of urban areas using satellite remote sensing data have been conducted primarily using the thermal-infrared band from Landsat Enhanced Thematic Mapper Plus (ETM+) data. As illustrated in Figure 13, Cairo shows a significant rise in surface temperature with a general trend of warmer urban areas versus cooler surrounding cultivated land.

In the future, urban climate change will be of importance to a larger and larger number of residents of the Arab world. With such a significant and rising fraction of the Arab world's population concentrated in urban areas, local climatic effects will be felt by a great number of people.

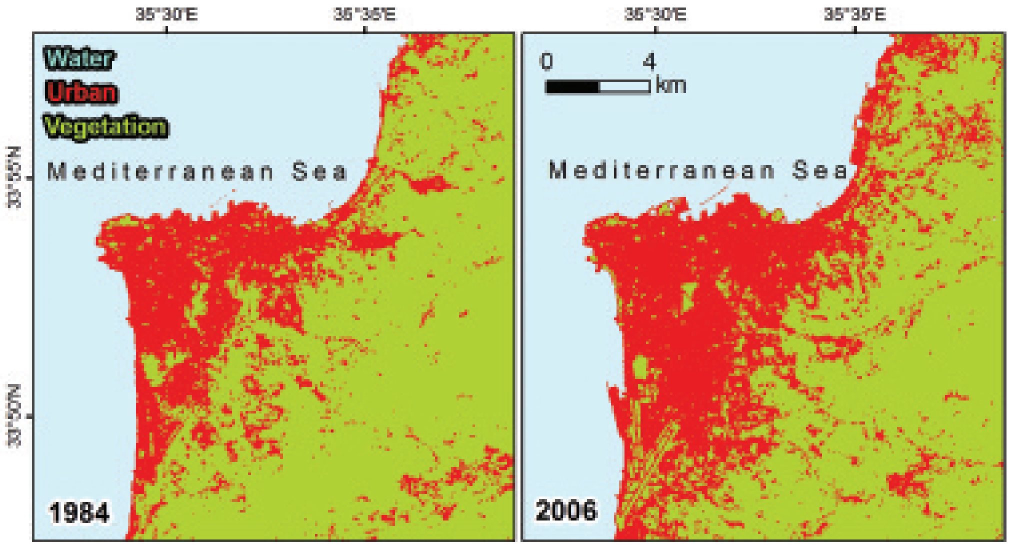
VI. DUST STORMS IN THE ARAB DESERTS

Aerosol pollution caused by dust storms can modify cloud properties to reduce or prevent precipitation in the polluted region. Aerosol containing black carbon can impact the climate and possibly reduce formation of clouds. The decrease in precipitation from clouds affected by desert dust can cause drier soil, which in turn raises more dust into the air, consequently providing a potential feedback loop to further decrease rainfall. Moreover, anthropogenic changes of land use exposing the topsoil can initiate such a desertification feedback process. (Rosenfeld et al., 2001)

Urbanization not only increases the local temperature but also creates industrial districts that cause atmospheric pollution and reduce local air quality. With the continuous build-up of climate change emissions in the atmosphere from unregulated industrial emissions, many desert regions will get hotter and drier in a phenomenon called the amplification effect; that is, already hot and dry places on Earth will become even more so. Consequently, dust storms in the desert will become more frequent and intense.

Research shows that dust storms are increasing

FIGURES 14, 15 **EXPANSION OF URBANIZATION IN COSMOPOLITAN BEIRUT BETWEEN 1984 AND 2006: 15.8% OF THE GREEN COVER WAS LOST**



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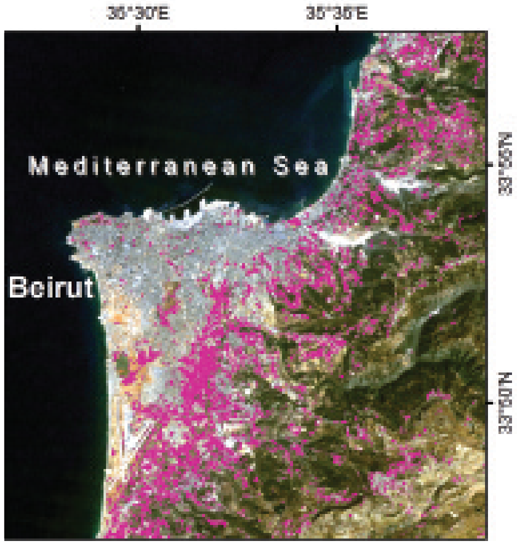


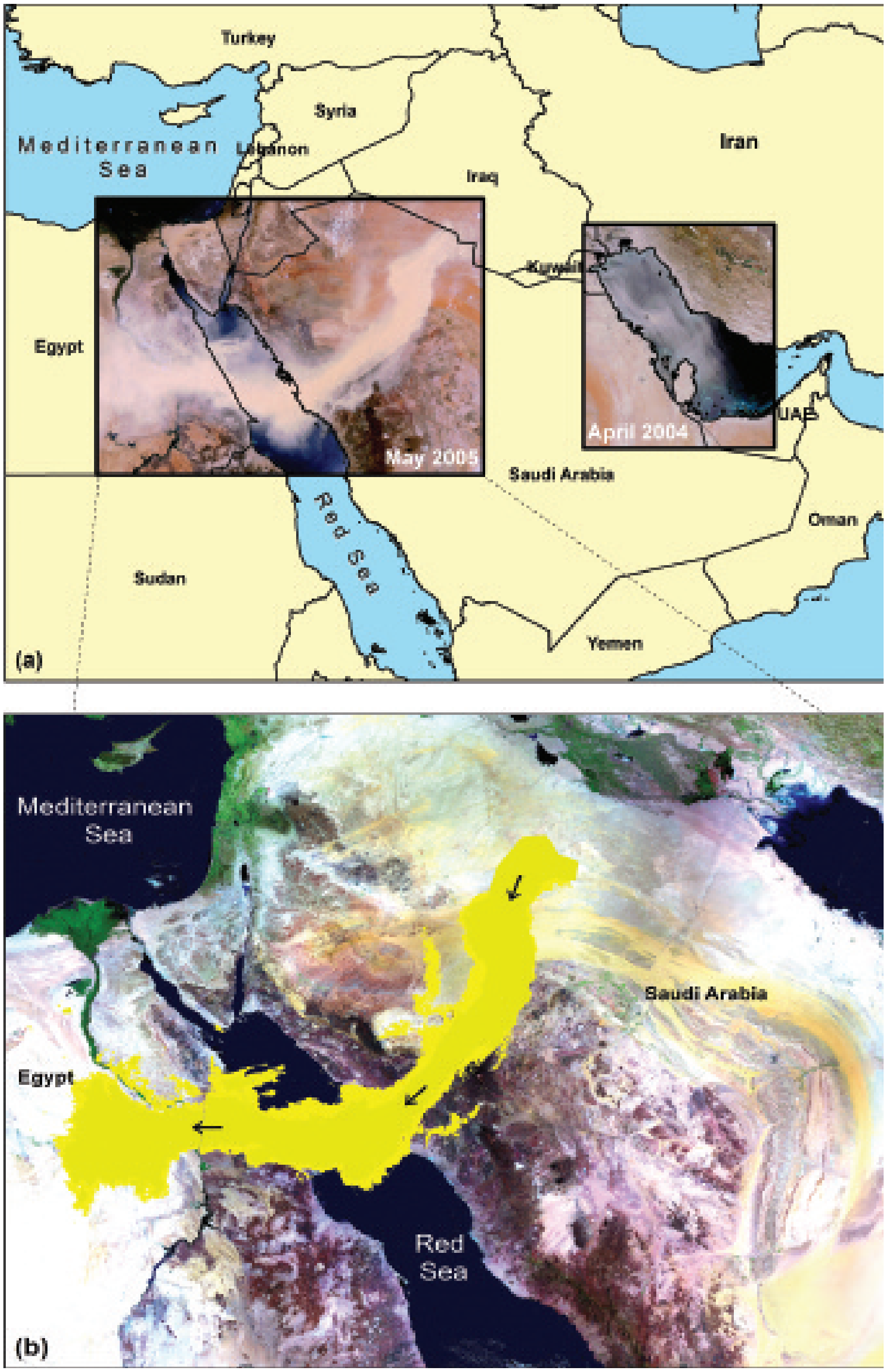
in frequency in specific parts of the world, including Africa and the Arabian Peninsula. For example, the annual dust production had increased tenfold in the last 50 years in many parts of North Africa. Dust storms are also accelerating in the Arab region due to the fact that local soil cover is being loosened by off-road vehicles (e.g., the effect of the Iraq wars), livestock grazing, and road development for oil and gas production, particularly in the Gulf region.

The availability of large and daily coverage satellite imagery by, for instance, the MODIS Terra and Aqua sensors enable us to monitor dust storms on a daily basis and identify their main source globally. For example, as shown in Figure 16a, a thick snake of yellowish dust originating from the border of Iraq with a southwest moving front can be clearly seen in one of the MODIS-Aqua images (acquired in May 2005). This storm is so thick that it hides a large part of the Red Sea beneath it. Image classification accentuates such phenomena and reveals the mega dimension of such dust storms; Figure 16b shows a storm which reached up to 1700 km in length. This storm crossed Saudi Arabia and all the way past the green ribbon of the Nile Valley to the western desert of Egypt.

Another example of a mega dust-storm is captured by a MODIS-Terra image (acquired in May 2004). Here, a thick pall of sand and dust can be seen blown out from the Iranian Desert over the Gulf and engulfing Kuwait, the eastern coast of Saudi Arabia, Bahrain, Qatar and United Arab Emirates (see Figure 16a).

FIGURES
16(a) 16(b)

16(a), LEFT: A MODIS-AQUA IMAGERY SHOWS A MEGA DUST STORM ORIGINATING FROM IRAQ IN 2005 16(a), RIGHT: A MODIS-TERRA IMAGERY ILLUSTRATES A THICK PALL OF SAND AND DUST BLOWING FROM THE IRANIAN DESERT IN 2004 16(b): SATELLITE IMAGE CLASSIFICATION DEMONSTRATES THE MEGA DIMENSION OF A DUST STORM THAT REACHED 1700 KM IN LENGTH. THIS STORM CROSSED SAUDI ARABIA PAST THE GREEN RIBBON OF THE NILE VALLEY TO THE WESTERN DESERT OF EGYPT



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VII. CONCLUSION

In the Arab world, segments of coastal areas are important and highly populated centres of industry, manufacturing and commerce. With its nearly 34,000 km of coastline, the Arab world is susceptible to sea level rise. The potential exposure of many of its countries and cities such as Alexandria, Dubai and many more to the impact of sea level rise may be fairly significant, based on today's socio-economic condition in coastal areas. After accounting for future development and population growth in these regions, sea level rise has been shown to pose important policy questions regarding present and future development plans and investment decisions.

Notably, urbanized sandy coasts have been extensively cited as particularly vulnerable if future development is concentrated close to the shoreline and if sensitive ecosystems exist in close proximity to these urbanized areas. Such regions will experience problems such as inundation, coastal erosion and impeded drainage. Moreover, the continuing rapid and dense urban development of many areas in the Arab world would result in a dramatic alteration of the land surface, as natural vegetation is removed and replaced by non-evaporating, non-transpiring surfaces. Under such circumstances, surface temperature of these areas will rise by several degrees. On the long term, such urban Heat Island effect (UHI) could have severe negative consequences on the local weather of the Arab region, which in turn would contribute significantly to global warming.

Furthermore, the increasing frequency of dust storms is one of the serious environmental challenges facing the Arab region. Such storms would induce soil loss, decrease of precipitation and agricultural productivity, dramatic reduction of air quality and ultimately affect humanhealth. Although it seems that we are not totally prepared to face all such destructive effects of the SLR, UHI and dust storms, recent advances in remote sensing, increased availability of high resolution space imagery and the accessibility to more detailed datasets of digital elevation, population and land cover-use, have all the potential to provide improved surveillance of such negative effects and their associated impacts on the entire Arab world. Such observational data can then be used as a solid basis upon which policies could be made.

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NOTE

Images produced and analyzed for AFED 2009 Report by E. Ghoneim at the Center for Remote Sensing, Boston University.