CRITICAL ASSESSMENT OF DISASTER VULNERABILITIES IN THE KINGDOM OF SAUDI ARABIA - STRATEGIES FOR MITIGATING IMPACTS AND MANAGING FUTURE CRISES

George Pararas-Carayannis

President, Tsunami Society International
Editor, Science of Tsunami Hazards
Retired Director, International Tsunami Information Center-UNESCO/IOC
Honolulu, Hawaii, USA
http://tsunamisociety.org   drgeorgepc@yahoo.com

ABSTRACT

Population expansion, technological improvements and economic growth in the Kingdom of Saudi Arabia have made the use of coastal zones and of selective inland areas more necessary than before. However, the same developments and advanced industries are contributing also to an increased threat of impact from natural, terrestrial and marine disasters. The combination of social and economic factors in the development – without adequate planning - makes the country particularly vulnerable. Also, man-made disasters such as chemical, industrial, nuclear and transportation accidents and conflicts, have the potential to create havoc on terrestrial and marine environments, resources and cultural sites. Slower term environmental disasters, with readily identified anthropogenic input, are also creating water and climate related hazards that will have a severe impact on the population of Saudi Arabia in the future. Equally threatening are potential biological disasters and epidemics. To mitigate future disaster impacts, a more critical and comprehensive approach must be taken in assessing specific vulnerabilities of each region of the country and in adapting and implementing needed new strategies. The present study reviews the potential impact of natural and man-made disasters in Saudi Arabia, where population growth and unprecedented development have taken place in the last few decades. Given the statistics of growth, there is little doubt that the impact of natural and man-made disasters will be significantly greater in the future. Already, there appears to be an alarming increase in losses from geological and weather-related

disasters. The costs of these disasters in terms of lives lost and damage to property have skyrocketed. Longer term, environmental disasters, with considerable anthropogenic input, are already contributing to global warming, sea level rise, climate change and to more frequent and intense weather-related hazards that will also affect the region. Man-made disasters, such as chemical, industrial, nuclear and transportation accidents could do even more harm in the future. Biological disasters and epidemics pose a threat as the population continues to grow. The present paper comments on the specific methodology that is needed to assess potential disaster vulnerabilities in Saudi Arabia, on the systematic application of disaster information resources and databases and, finally, on needed strategies that can help mitigate future losses and manage more effectively potential future crises.

INTRODUCTION

In the last 30-40 years there has been tremendous population growth and significant development of inland and coastal areas of Saudi Arabia. According to U.N. statistical reports, the 2012 population was 22.7 million but expected to increase to 44.9 million by 2050. This population explosion will take place mostly in the existing cities. Given such statistics of growth and increases in population density, the impact of natural and man-made disasters in cities of Saudi Arabia will be significantly greater in the future. Already, there appears to be an increase in losses from geological and particularly from recent weather-related hazards.

The present paper summarizes some of current hazards and vulnerabilities that are threatening Saudi Arabia and recommends policies, strategies and technologies that will result in better crises management practices that will help mitigate the adverse effects. But before reviewing Saudi Arabia's vulnerabilities to hazards and disasters and suggesting adaptation of new technologies for disaster management, we must review the country's unique geographic and geotectonic setting.

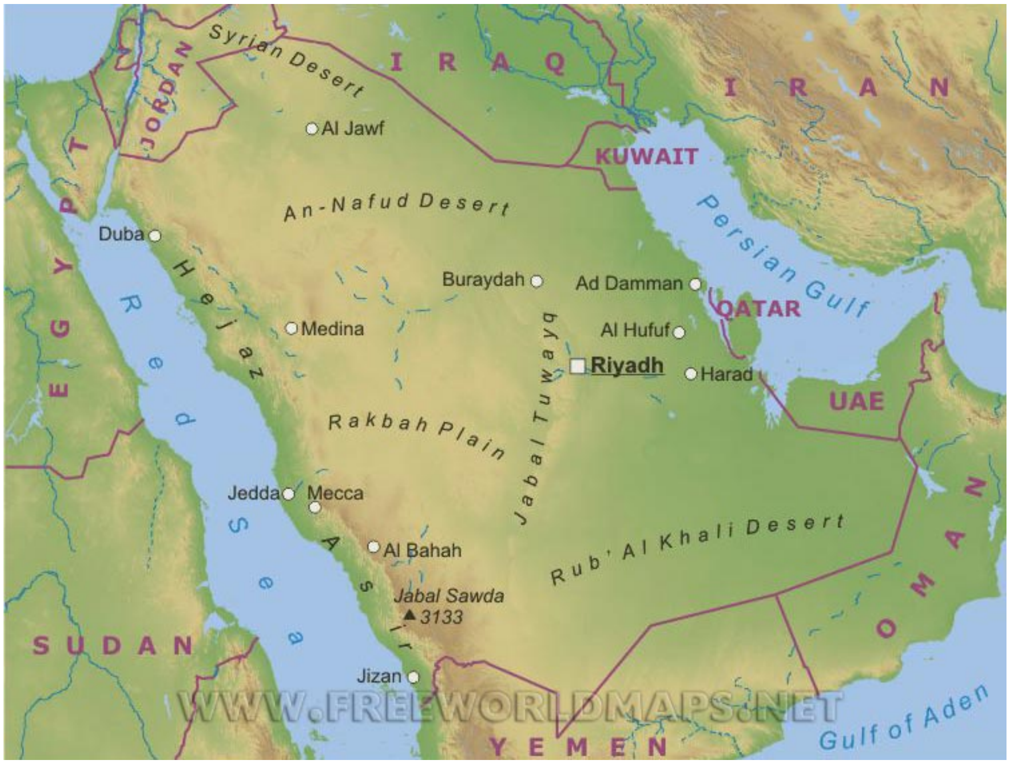

Figure 1. Physical Map of Saudi Arabia

GEOGRAPHIC AND TECTONIC SETTING OF SAUDI ARABIA

Saudi Arabia covers most of the Arabian Peninsula. Most of the country is desert. The central region consists of an eroded plateau, which is mostly arid and hot in the summer and cold in the winter. The western region is mountainous, except for the coastal plain bordering the Red Sea. The southern region is also mountainous and receives enough rainfall to support agriculture. The eastern part of Saudi Arabia is flat and sandy, bordering on the Arabian Gulf and possessing most of the country's vast oil resources. The capital of Saudi Arabia is Riyadh. On the Red Sea, Jedda is an important port city and Jubail and Yanbu are important industrial cities. Saudi Arabia's most important cities are Mecca (Makkah), the birthplace of the Prophet Mohammed and Medina, to which the Prophet moved in 622 AD. These are the two holiest cities of Islam. Bordering countries are Iraq, Jordan, Kuwait, Oman, Qatar, UAE, and Yemen. The Kingdom of Saudi Arabia takes up most of the Arabian Peninsula (Fig 1). Its geography varies from coastal regions in the east and west, with mountainous regions to the southwest. The Rub' al Khali desert, which extends along the southern border, is mainly uninhabitable.

Tectonic Setting

Saudi Arabia is located on the Arabian Plate, which has been moving northward over millions of years and colliding with the Eurasian plate (Fig. 2). The Arabian Plate consists mostly of the Arabian Peninsula. To the North, it extends to Turkey and has a complex convergent boundary with the Anatolian and the Eurasian Plates. To the east it borders the Indo-Australian Plate along the Owen Fracture Zone. To the South, it borders with the African Plate. Finally to to the west, it borders with a left lateral fault boundary with the African Plate known as the Dead Sea Transform (DST) and a divergent boundary with the African Plate called the Red Sea Rift which extends to the full length of the Red Sea.

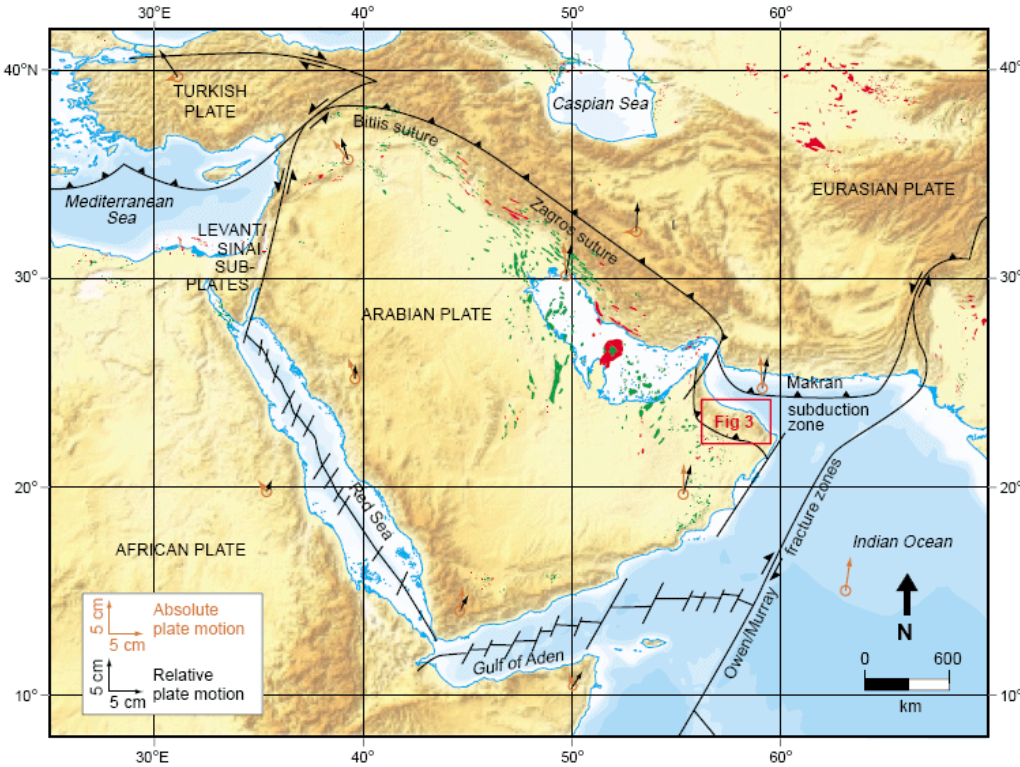

Fig. 2. The Arabian Plate (source of map: Al Lazki, 2002)

Tectonic and Geodynamic Evolution - The Arabian Plate was part of the African plate during much of the Phanerozoic Eon (Paleozoic – Cenozoic) until the Oligocene Epoch of the Cenozoic Era. Red Sea rifting began in the Eocene, but the separation of Africa and Arabia occurred in the Oligocene, and since then the Arabian Plate has been slowly moving toward the Eurasian Plate.

The collision between the Arabian Plate and Eurasia is pushing up Iran's Zagros Mountains Because the Arabian Plate and Eurasia plate collide, many cities are in danger such as those in southeastern Turkey (which is on the Arabian Plate). These dangers along the northern boundary include earthquakes, tsunamis and volcanoes.

Formation of the Arabian/Iranian Foreland Basin and of Oil Reserves

The Arabian plate movement and collisions were responsible for the formation of the tremendous oil deposits in the region. Saudi Arabia has about 161 giant oil deposits along the Persian Gulf. The huge oil reserves concentrated in a large foreland basin, which was formed during the Late Cenozoic collision of the Arabian Peninsula with Eurasia (Fig. 3).

Fig. 3. Major Oil Fields in the Arabian-Iranian Basin Region (map source: Encyclopedia Britannica)

The downward flexure of the Arabian Peninsula beneath the Zagros Mountains of Iran/Iraq was caused by the northeastward consumption of the Tethys Ocean at the Zagros suture zone (RE). Additional causes of this flexure were the eventual Cretaceous-recent convergence and collision of the Arabian plate against the Eurasian plate. This protracted convergent event has created the Persian Gulf and the Mesopotamian lowlands as a sag in the foreland basin, as well as the formation of the Zagros Mountains, with a culmination of fold-thrust deformation during Miocene and Pliocene time.

However, other than minor tilting, large areas of the foreland appear to be completely undisturbed by the Zagros-related convergent deformation, as manifested in the variety of giant-field shapes. For that reason, formation of elongate oil giants parallel the folds and thrusts in the Zagros Mountain and the foreland basin has been geologically classified as a continental collision margin, while those giants to the southwest were counted as continental rifts and overlying steer's head sag basins.

The initial hydrocarbon-formation occurred in the following way. The basal stratigraphic section underlying the present-day foreland basin was deposited along a Cambrian-Permian passive-margin setting along the southern Tethys margin. Deeply buried salt, possibly deposited in Cambrian rifts, was activated by small-displacement basement faults during Permian to Jurassic time. These gave rise to salt domes, ridges and diapirs, forcing folds in the overlying sedimentary section, which include some of the largest giant oil fields, such as "Ghawar". These folds are at a high angle to later folds and thrusts related to the Zagros convergence. Source rocks in this basin phase include Cambrian-to-Permian units, with the main reservoir in the Permian.

A second hydrocarbon-formation period occurred from the Triassic through Tertiary, with Middle Jurassic source rocks and Upper Jurassic reservoirs. Migration is primarily upward from underlying source rocks in giant fields that are removed from the Zagros deformation. Structural traps formed in the area adjacent to the Zagros fold-belt and relate to early collisional effects in Eocene and younger time.

POTENTIAL NATURAL AND MAN-MADE DISASTERS IN SAUDI ARABIA

Earthquakes, tsunamis, hurricanes, volcanic explosions, floods or droughts have always been part of the natural cycle. In the last two decades such natural disasters have killed close to 3 million people worldwide, disrupted over 820 million lives, and caused more than $100 billion in property damage.

To the heavy toll of natural disasters, we must also add the impact of man-made hazards. Accelerated changes in demographic and economic trends caused by population growth have disturbed the delicate balance between ecosystems on our planet, have seriously affected human health, and have increased the risk of human suffering, death and destruction. The slower developing, man-made disasters include pollution of the atmosphere and of the seas, destruction of rain forests, alterations of sensitive ecosystems, or the destruction of the ozone layer. Climate changes we do not fully understand, like global warming or sea level rise, are slow disasters in-the-making that will have a long-term adverse effect on future generations.

Prior to discussing existing vulnerabilities in Saudi Arabia to natural and man-made disasters, some clarification of terms must be made. A hazard can be thought of as a potential risk which endangers human life, health, property or the environment. If this risk leads to an actual incident, then it is referred to as an emergency or a crisis situation. If the damage from such incident is overwhelming and destructive, then it is labeled as a disaster. The disaster could be caused by natural forces of nature or by human factors.

Unfortunately, there is no official central database listing historic hazards and disasters that have struck Saudi Arabia in the past, other than scarce information from miscellaneous sources such as local newspapers or the International Disaster Database (IDD) of the World Health Organization (WHO). According to these sources and mainly IDD, the incidence of natural hazards and disasters in Saudi Arabia has been rising.

Vulnerability of Saudi Arabia to Natural Hazards and Disasters

As stated, natural disasters are rapid changes that affect human safety and property. Weather-related natural disasters include cyclones (typhoons, hurricanes) and associated surge flooding, tornadoes, heavy thunder storms, flash flooding floods, mud and rock slides, high winds, hail, severe winter weather, extreme high temperatures, drought and wildfires. Major geological disasters include earthquakes, volcanic eruptions, landslides and tsunamis. Most of the naturally occurring disasters are inevitable because they are beyond human control and cannot be prevented. Often, they are unpredictable, strike without warning and can result in great loss of life and destruction to property in a very short period of time.

The impact of natural disasters in Saudi Arabia has not been extensive until now. There is no much or little information on geologic disasters such as earthquakes, volcanic eruptions and tsunamis. However, other natural disasters, have been more frequent. Longer term, environmental disasters, with considerable anthropogenic input, are already contributing to global warming, sea level rise, climate change and to more frequent and intense weather-related hazards, which also will impact Saudi Arabia in the future. Given the anticipated population and industrial growth in the country in the next few decades, it appears that the impact of natural and man-made disasters will be significantly greater in the future. The following sections provide a brief overview of past natural and man-made disasters in Saudi Arabia and what may happen in the future.

Earthquakes, Tsunamis and Volcanic Eruptions - Geologic disasters such as earthquakes, volcanic eruptions and tsunamis do not present a significant or frequent threat to Saudi Arabia. However, the Arabian Peninsula has been affected by tsunamis in the past (Jordan, 2008). As described, the Peninsula is bounded by the Persian Gulf on its northeast side, the Red Sea on its west side, and the Arabian Sea, the Gulf of Aden, and the Indian Ocean to its east and south. Each of these areas is very different geographically, tectonically and bathymetrically. Most of the earthquakes occur along the collision boundaries of the Arabian Plate and the country, being primarily in the center of the Peninsula, is somewhat protected. Almost all of the recorded tsunamis along the Arabian Peninsula have occurred on its eastern and southern edge, some, such as the one formed by the 1945 Makran earthquake, or the 1883 eruption of the Karakatau volcano, or the 2004 Sumatra event, were extremely destructive (Pararas-Carayannis, 2003; 2005; 2006).

The Indian Ocean is the most likely source area for future destructive tsunamis that would impact the Arabian Peninsula. However, small magnitude earthquakes can occur along the Red Sea Rift Zone and their potential for destructiveness or the generation of a local tsunami should not be overlooked. In fact two, localized tsunamis have been recorded in the Red Sea. Another doubtful, tsunami was generated in the Persian Gulf. Most of the major earthquakes occur along the Zagros mountain range, and do not have an impact on Saudi Arabia. However an Iran earthquake close to the shore has the potential to generate a tsunami in the Gulf that could impact Saudi coastlines. Similarly, volcanic eruptions do not pose a major threat, as most of the volcanoes are underwater and located along the Red Sea Rift Zone.

It was readily believed that northwest Saudi Arabia was geologically quiet, as few earthquakes and volcanic eruptions were recorded there in the past millennium. However, a volcanic eruption is possible in the Northwest border of the country, where there has been recent unusual seismic activity. In fact, between April and June 2009, a swarm of more than 30,000 earthquakes struck the lava field of “Harrat Lunayyir” near the corner of Saudi Arabia closest to Egypt. This indicates that this region is presently volcanically active and that magma material may be moving upward. The lava field of “Harrat Lunayyir” is part of a "lava province" roughly 70,000 square miles (180,000 square kilometers) in size (Alamri, 2010) that began forming 30 million years ago when the Arabian tectonic plate begun splitting from Africa. It is this rifting that created the Red Sea and “Harrat Lunayyir”, which was previously considered inactive because of its location on the margins of the continental rift, nearly 120 miles (200 kilometers) away from the active spreading center o beneath the Red Sea. The Red Sea rift itself is a very active with a chain of underwater volcanoes down the middle of it. Furthermore, when continents are being pulled apart, as it has been happening along the Red Sea rift, there may be upward intrusions of magma on the shoulders of the rift which may create surface faulting and even initiate volcanic eruptions. The latest recorded earthquake occurred near the Gulf of Aquaba along the Jordan-Saudi border on 8 October 2012. Its magnitude was only 3.9 and its focal depth was 8 km.

Floods **–** Floods are the most frequent events in the country that account for 7 of the 10 most damaging disasters between 1900 and 2010. This statistic on floods is rather surprising, in view of the fact that rains have been relatively scarce in Saudi Arabia. However, the country’s vulnerability to floods has been actually linked to the infrequency of floods, which resulted in the under-development of proper drainage systems in most cities. Also, many of the important cities vulnerable to floods are located on low elevations, surrounded by mountains. Heavy rainfall in the mountains drains the water to the cities below – often as flash floods - since there is no proper drainage. Major floods, which occurred in the country from 1964 to 2011, resulted in significant losses of lives. Flood disasters turned into catastrophes and some occurred as recently as 2009 and 2011.

Floods may become more frequent as a result of climate variability – leading to heavy economic losses and spikes in food insecurity. Sea level rises of up to 0.5 meters may be also expected by the end of the millennium as a result of global warming.

Cyclones and Cyclone Surges **-** Until 2007 no cyclones were known to have ever entered the Gulf of Oman or the Gulf. The region is simply not prepared for the high winds of a cyclone or the associated surges that could be generated. Such an event within the Gulf – if ever it occurred - could be extremely destructive to oil shipping facilities. However, from 1 to 4 August 200, tropical Super Cyclone Gonu - the strongest on record – developed in the Arabian Sea and headed towards the Gulf of Oman and the Hermuz Straits. Gonu’s storm surge and storm wave impact caused considerable coastal damage and flooding. Figure 4, below illustrates the cyclone’s trajectory path.

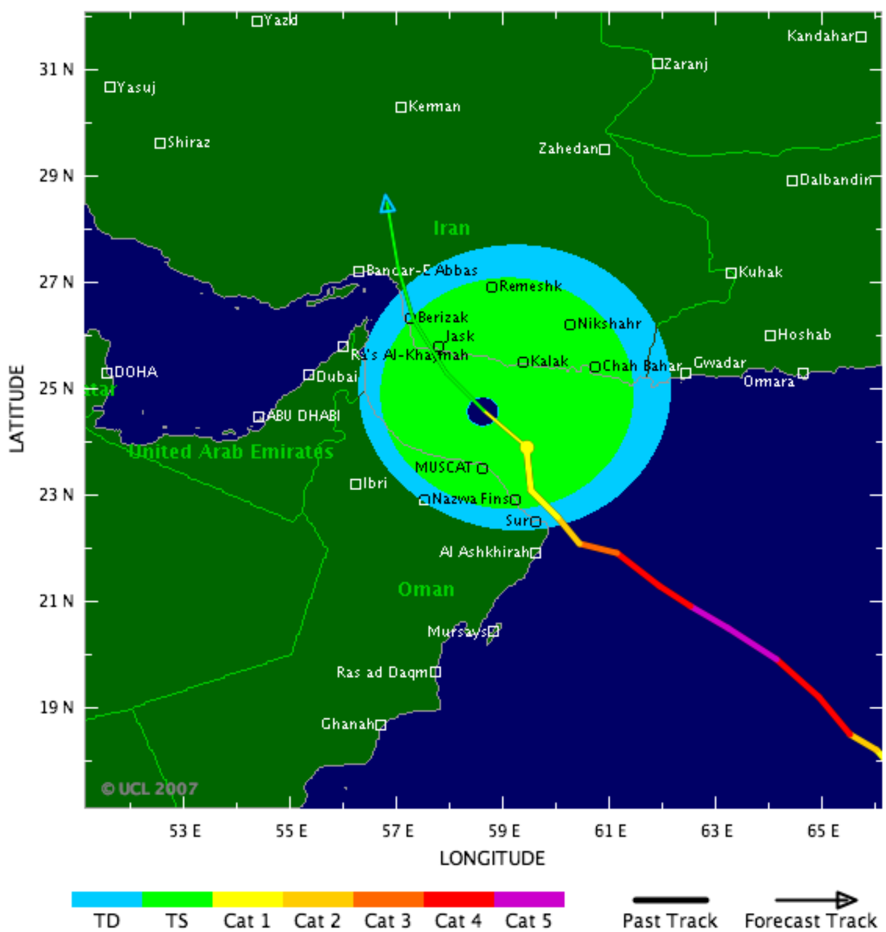

Fig. 4. Trajectory path of the 2007 Cyclone Gonu (Internet graphic).

The high water marks peaked at Ras al-Hadd at the eastern tip of Oman and exceeded 5 m (Fritz et al., 2010). Although no surges are known to have occurred within the Gulf, given the cyclone's radius and landfall, it is possible that strong winds may have been experienced not only in Oman but also in the Eastern coasts of the United Arab Emirates. Considering that the region has never experienced a cyclone previously, let alone a strong one, it is highly unlikely that the oil loading facilities or platforms were constructed to withstand the forces - both wave action and wind force - that will be experienced if a cyclone comes from a different direction and enters the Gulf. Significant, damage will occur. How much long-term damage, and the volumes associated with it - cannot be determined at this time.

Dust Storms and Strong Winds - Dust storms and strong winds are also environmental hazards that occur with frequency on the Arabian Peninsula (Fig. 5). Strong winds and dust storms from desert margins are changing both the local and global climate and also impact adversely on local economies. In recent years, major cities in Saudi Arabia, such as Riyadh and Jeddah, were struck by dust storms, which disrupted road traffic, caused automobile accidents, downed trees, forced the closing of schools and brought public life almost to a standstill.

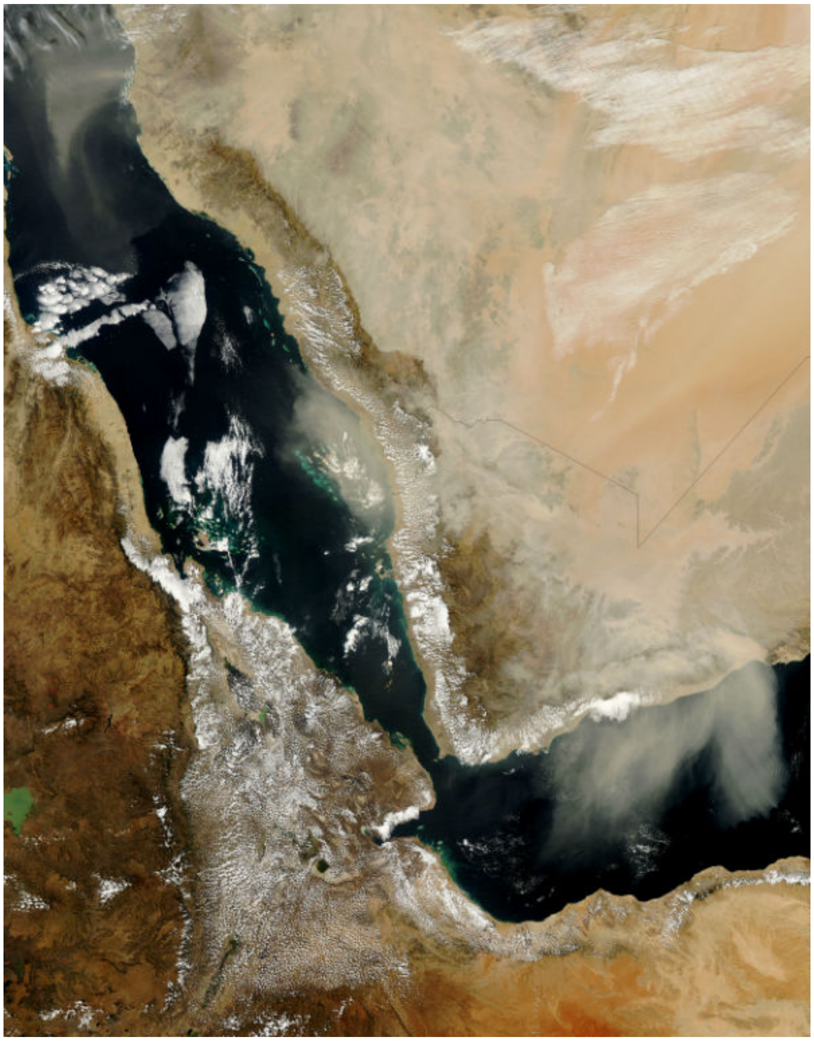

Fig. 5. Dust Storms over the Arabian peninsula (Credit: Jeff Schmaltz MODIS Land Rapid Response Team, NASA GSFC)

Strong winter winds are also hazards with frequent occurrences in Saudi Arabia. These winter “Shamals” are strong northwesterly winds, which blow over the Persian Gulf states. They are caused by a strengthening high-pressure system over the peninsula and in combination with a deep trough of low pressure east of the Persian Gulf. This pressure gradient results in strong northerly winds which blow over the Gulf, sometimes for extended periods of time. All of these weather phenomena can be readily forecasted and appropriate measures can be taken to mitigate their impact.

Vulnerability of Saudi Arabia to Long-term Climate Change Disasters

Globally, climate is expected to become more extreme in the near future, but more so for the arid countries of the Arabian Peninsula. New climate change risks are emerging at a much faster rate, including the prospect of a world that is four degrees hotter, and resilience built up over years is being severely tested, the World Bank warned. Other reports indicate that over the past 30 years, climate change disasters have affected millions of people in the Arab world, costing about $12 billion directly and many multiples of that indirectly.

The projected impact of climate change and its related disasters is expected to be great. Extreme weather could affect both the tourism industry and agriculture in Saudi Arabia, the latter already under severe climate stress. Recent trends suggest that dry regions in the country are becoming drier and flash floods have become more frequent. Also, the data shows a steady five-fold increase in the number of flash floods from 1990 to the present. Flash floods in the region have increased due to more intense rainfall, affecting twice as many people as 10 years ago.

The combination of higher temperatures, lower rainfall and increased frequency of drought could cause more crop failures and lower yields. Also, it has been reported that over the next 30-40 years, climate change is likely to lead to a significant reduction in household incomes. For example, it has been reported that about 40 per cent of jobs in the Arab region are derived from agriculture. By 2050 production may decline due to less rainfall and hotter conditions. About 100 fruit, crop, and livestock species were domesticated in the Arab region. More than 30 per cent could face extinction simply from warming of just 1-2°C.

A harsher climate threatens livelihoods in Saudi Arabia and the entire Peninsula region. The impact on people's livelihoods and wellbeing will be greater – especially for the poor who are least able to adapt. Sustainable development will need a reduction of the country's vulnerability to climate change. This will require a concerted action on multiple levels to establish climate change as a national priority. It will be important for Saudi Arabia to take actions, at both at the national and regional level, to increase climate resilience.

High Temperatures - The impact of climate change will be acute in the Arabian peninsula and region and immediate action will be needed to avoid the projected consequences of worsening water shortages and rising food insecurity, according to a new World Bank report on climate change. The year 2010 was globally the warmest since records began in the late 1800s, with 19 countries setting new national temperature highs. Five of these were Arab countries, including Kuwait, which set a new record at 52.6 °C in 2010, only to be followed by 53.5 °C in 2011.

Vulnerability of Saudi Arabia to Man-Made Disasters and Epidemic Outbreaks

Man-made disasters include wars (conventional, biological, chemical or nuclear), toxic material emissions and chemical spills (from trains, industrial plants or ships), riots or other civil disorders, potential future nuclear plant melt down or other nuclear disaster, acts of terrorism, fires and pollution. It is outside the scope of this report to elaborate on all the above stated man-made disasters, so only the most common and frequent of these will be addressed.

As previously explained, in the last two decades we have witnessed a remarkable global increase in the frequency and severity of weather-related disasters such as cyclones, tornadoes, floods, wildfires and droughts. Although these are considered to be natural disasters and we discussed them as such in a previous segment of this report, human input in the form of greenhouse gases emitted by industries into our planet's atmosphere has been blamed for climate change, global warming and sea level rise. Thus, to some extent these environmental disasters may be also considered as partly man-made. It appears that a new era of super-disasters has made its appearance globally. For example in one year alone in 2005, there was a record of 26 storm systems in the Atlantic and most of them reached hurricane intensities. Nothing similar had occurred in the past. Thus, the possible contributing human factors - anywhere in the world - can no longer be ignored. The seas are rising, the planet is getting hotter and there is an explosion in population and development in all regions of the world. Saudi Arabia is also vulnerable to all the climate changes, regardless of how these are introduced.

Global Warming – As previously stated, rising populations and the cumulative and synergistic effects of environmental degradation appear to have a significant effect in global warming and appear to have increased the frequency and intensity of weather-related disasters. Intense weather related disasters have caused an increase of the human death toll. According to the World Disasters Report, weather related disasters in one year (1998) resulted in the deaths of thousands. Hurricane Mich killed 10,000 in Central America. Indonesia experienced the worst drought in 50 years. Floods in China affected 180 million people. Fires, droughts and floods - blamed on the El Nino weather phenomenon - claimed a total of 21,000 lives and caused more than $90 billion in damages. The more recent statistics are even more overwhelming.

The on-going climate change and accelerated global warming that our planet has been experiencing for the last few decades, represent the greatest long term disasters that threaten present and future generations. Unfortunately, these slow, global changes cannot be easily measured, quantified or mitigated. Although international treaties such as the Kyoto Protocol have been signed by most countries to reduce greenhouse gases, there has been no significant reduction in atmospheric concentrations. In fact, the world population increases have placed higher demands for the use of fossil fuels and the amounts of greenhouse gases in our atmosphere are increasing.

The impact of global warming in Saudi Arabia cannot be readily assessed or quantified. However, like any other country in the region, the impact is expected to be even greater in the future. Of particular concern for Saudi Arabia should be the climate change driven increase of flooding hazards along urban areas in coastal zones, in the form of storm surges and of flash floods inland - particularly in areas where extensive and unregulated urban sprawl has taken place.

Epidemic Disasters **-** To the list of disasters, whether man-made or natural, rare disasters include pandemic disease outbreaks (like bird flu). In fact, the looming health hazards of diseases and potential pandemics such as the Avian Flu may not be all that rare. About four pandemics occurred in the 20th Century. In 1918 to 1919 the so-called

"Spanish Flu" or great influenza pandemic - which is believed to have originated in Asia - infected an estimated one billion people and claimed as many as 50 million lives. Presently, the Avian Flu and the new strains that have developed – if not effectively contained - have the potential of becoming the world's worse disasters. It is estimated that a pandemic of the avian flu or its subsequent strains could cause the death of 150 million people. Already this year, 2013, the flu has reached epidemic proportion in many countries.

Saudi Arabia is particularly vulnerable to epidemic disasters and their potential impact should not be overlooked. Biological disasters and epidemics are hazards that may greatly threaten the country in the future, as the population continues to grow and there is a high concentration of worshippers in major cities during certain times in the year. With all the crowding during mass gathering seasons, emergency preparedness activities take longer to establish and are more difficult and expensive to run in an already crowded city such as Makkah. Basically the nature and timing of the high-risk seasons in Makkah render the endemic population and the visitors more vulnerable to all types of anthropogenically-generated epidemic diseases. For example, in a two-year period in 2000-2001 there were three epidemic disasters in Saudi Arabia with many reported deaths.

STRATEGIES FOR MITIGATING DISASTER IMPACTS AND MANAGING FUTURE CRISES

Since both natural and man-made disasters are on the increase, strategies must be devised for mitigating their impact and in managing crises. In the following section, some of the needed strategies are briefly described.

Earthquakes and Tsunamis – As already mentioned in this report, earthquakes and tsunamis do not pose a significant threat in Saudi Arabia. However, since nuclear power plants will be built in the near future, a critical assessment of tsunami vulnerability should be conducted for potential earthquake sources along the Gulf coast of Iran. The specific methodology for assessing, earthquake, tsunami and storm surges vulnerabilities has been described adequately in the scientific literature and in reports to the US Nuclear Regulatory Agancy (Pararas-Carayannis, 1986, 1988, 2006). Each earthquake, each tsunamigenic region and each hurricane (cyclone), has its own characteristic mechanisms that need to be evaluated independently for proper risk assessment. Analysis of the seismotectonic characteristics of each region can help assess the impact of future disasters, develop realistic scenarios of vulnerabilities and adopt effective strategies for informed warnings and disaster mitigation. Proper evaluation of geotectonic parameters would result in a more effective decision-making process on whether to issue a local warning. Setting safety guidelines for the impact of hurricane surges in constructing nuclear power plants is an essential part of mitigating any possible risk (Pararas-Carayannis, 1975). Such understanding and analysis would also result in developing better strategies for zoning risks, land use and overall disaster mitigation.

Volcanic Eruptions - As previously stated, a volcanic eruption is possible in the Northwest border of the country, where there has been recent unusual seismic activity. There is also a possibility that one of the underwater volcanoes along the Red Sea Rift may erupt and break the sea surface in the future. The prospect of a volcanic disaster along the Red Sea Rift should not be overlooked. Even though the risk is small at the present time, strategies for mitigating future impact of a volcanic disaster should include the monitoring of precursory eruptive processes. Additionally, strategies must include studies of geomorphologies and flank instabilities of individual volcanoes – including those underwater - and the mapping of risk areas in the country where eruptions or volcanic instability can contribute to a landslide - with or without a triggering event. The best strategy for the mitigation of this type of disaster is to properly monitor on-going activity and to legislate for appropriate land use that would not allow development in risk areas.

Strategies for Assessing Climate Change Vulnerabilities

Terrestrial and extraterrestrial factors contribute to global climate change. Various models predict significant temperature rises for the planet in the near future. As stated, complex anthropogenic interactions appear to contribute cumulatively and to accelerate the on-going natural process of global warming. Extensive deforestation of large surface areas of the earth has resulted in significant changes in the water and radiation balance of the planet. Other apparent adverse anthropogenic impacts on climate include land-originating pollution due to increases in urbanization and industrialization and increases in the use of fossil fuels. The resulting global warming and the rising sea level will have serious short and long-term impacts on human and animal life on our planet. Although, all of the above contributing factors to changes of climate may be occurring further away, and as discussed earlier, there will be a significant impact in Saudi Arabia.

The effect of global warming on weather patterns will be responsible for an apparent increase in the frequency and intensity of weather-related disasters on the Arabian Peninsula. Weather-related disasters will be impacting with relentless frequency and intensity and will take a heavy toll in future years. Similarly, man-made disasters caused by chemical spills, civil strife and wars, not only constitute a clear and ever present danger for the region, but may also have cumulative long-term effects on climate. While all areas of the world are affected by climate change and by natural, weather-related or man-made disasters. It is the lesser-developed countries, which will experience losses in human lives and economy disproportionate to their resources. Often, such major natural and man-made disasters can be expected to result in complex humanitarian emergencies that will compromise seriously the socioeconomic development in the region and will escalate demands on rapidly diminishing resources. To alleviate the potential problem in Saudi Arabia, it will be important to develop scenarios of such major disasters and develop proper planning for management of crises.

In view of the pending challenge for Saudi Arabia, a cautionary governance approach must be taken to properly assess problems and risks caused by climate change and by natural, weather-related and man-made disasters. To mitigate effectively adverse impacts, response action plans must be drawn, advocated and put into effect. Also, there must be adherence to the international treaties on the emissions of greenhouse gases that contribute to climate change and to increases in the frequency and intensities of weather-related disasters. To ensure the protection of human life and property in Saudi Arabia, it will also be necessary to evaluate the short and long-term risks of potential disasters. International cooperation for disaster mitigation awareness, education and preparedness, such as that promoted by the International Decade on Natural Disaster Reduction (IDNDR) in the 1990's, must continue with emphasis on the adverse impact of climate change and weather-related disasters.

Finally, the development of strategies for mitigating the impact of weather-related disasters must be based on good understanding of what happened in the past. Thus, proper assessment of potential risks is the first essential step in the planning process and in designating susceptible areas. Building shelters in safe areas can help mitigate the impact of storm disasters in low-lying regions subject to flooding. Better drainage systems must be constructed Also, planning for quick post-disaster recovery is essential in keeping the death toll low. Imposing higher building standards and adopting better land use policies are effective strategies in mitigating the impact of a similar disaster. Finally, strategies must include the use remote sensing, satellite photography and other types of imaging techniques that can successfully estimate storm tracks, wind velocities, landfalls and the mathematical modeling of storm surges (Pararas-Carayannis, 1975, 1993, 2004).

Strategies for the Protection of Future Nuclear Power Plants

As of 2009, the six member states of the Gulf Cooperation Council (GCC) - Kuwait, Saudi Arabia, Bahrain, the United Arab Emirates (UAE), and Qatar have been producing a total of 416 billion kWh per year, all from fossil fuels and with 5-7% annual demand growth. Given the rate of the region’s projected growth, the currently produced amount of electricity will not be sufficient in the future. There is also a large demand for nuclear powered desalination, currently fuelled by oil and gas. Production of water could also be a major factor in offsetting the impact of global warming on the generation of weather related disasters and in improving agricultural production. Thus, to meet this additional demand for desalinated water and reliance on depleting hydrocarbon fuels, Saudi Arabia plans to augment the electrical capacity of the region by constructing many nuclear power reactors over the next 20 years. This is a very positive development, but one that may also increase the region’s vulnerability to potential accidents and the disposal of radioactive wastes.

Although new safer technology for nuclear power plant construction has been developed and the region does not face the type of disaster that caused the 2011 Fukushima Daichi nuclear plant disaster in Japan, the IAEA guidelines must be followed and a complete and comprehensive analysis must be made for each of the selected sites of nuclear power plant construction. Although, earthquakes do not occur on the western side of the Gulf, earthquakes on the other side along Iran’s coast could generate a tsunami that may have an impact on the Gulf States. Furthermore, the safety in the sitting and elevation of nuclear power plants in coastal areas should be of great concern regardless of the adequacy of design.

Such safety of nuclear power plants requires a careful evaluation of what potential effects a tsunami or cyclone surge could have on a nuclear power plant's cooling systems – and the adequacy of elevation of the cooling pumps and associated heat exchange units must be carefully examined for both tsunami and surge impacts, as routinely examined by the US Nuclear Regulatory Agency and the International Atomic Energy Agency (Pararas-Carayannis, 1975, Sewell and Pararas-Carayannis, 2012).

A cooling system's failure - as that which occurred at the Fukushima Daiichi Nuclear Power Plant - could result from tsunami inundation and cyclone generated surge flooding. Pumps as well as backup systems could fail. A proper evaluation of safety for nuclear power plants (NPPs) should include the assessment of the following elements (Sewell and Pararas-Carayannis, 2012)

Definition and Importance of External Hazards for NPPs
External Hazards Assessment for NPPs
Special Considerations & Unique Challenges
Applicable Existing Safety Guidance for NPPs
Screening and Evaluation Approaches and Bases
Deterministic Assessment for External Hazards
Probabilistic Assessment for External Hazards

According to IAEA definition, external hazards originate from sources located outside of the site of the nuclear power plant. Examples of external hazards include:

Seismic hazards (not an issue for the Gulf States region)
High winds and wind-induced missiles
External floods *including tsunamis*
Other severe weather phenomena
Off-site transportation accidents
Off-site explosions
Releases of toxic chemicals from off-site storage facilities
External fires (e.g. fires affecting the site and originating from nearby sources)

External Hazards can often be the dominant contributor to the risk of nuclear plant failure (e.g., core damage, or significant radiological release). For example, seismic events are a particularly severe challenge to NPPs, and typically cannot be ruled at any location for return periods of interest (i.e., up to 10 million years). Recent experience at the Fukushima-Dai'ichi NPP has demonstrated tsunamis to be an external hazard requiring improved awareness and safety assessment risk management.

There are additional special considerations and unique challenges in evaluating external hazards. For example High Severity – Common Cause are scenarios, which have the potential to adversely affect many components of the NPP or, often, the entire plant, as was the case with the Fukushima-Daichi catastrophe.

High uncertainty is another special consideration, as for example when experience data is often lacking and uncertainties must be *systematically quantified.* Broad and diverse phenomena cover several disciplines and areas of expertise, often leading to the temptation to minimize or ignore the threat (e.g., it is common that analysts or decision makers to prematurely eliminate or screen-out events outside of their immediate expertise).

In brief, NPPs such as those planned for construction in Saudi Arabia and other Gulf States must meet all the applicable IAEA safety guidelines of deterministic and probabilistic safety assessment, the newly adapted ASME/ANS standard, and the US NRC's Best Practices from IPEEE Implementation Experience. Additionally the planned NPPs must meet all the applicable IAEA guidance on procedures for flood hazard analysis, which includes tsunamis, seiches, storm surges, in addition to river flooding (not applicable in this region). In spite of the IAEA guidelines, the entire safety analysis often becomes a subjective process, so care should be exercised in avoiding this type of bias in the evaluation. However, it is outside the scope of this presentation to comment further on additional potential problems associated with NPP safety assessments that must be taken into consideration.

APPLICATION OF DISASTER INFORMATION IN MITIGATING FUTURE LOSSES AND MANGING CRISES - A SUMMATION

The methodology for assessing the potential risks that threaten Saudi Arabia requires adequate understanding of the physics of each type of potential disaster - whether natural or manmade - a good and expeditious collection of historical data of past events, and an accurate interpretation of this data as to what the future impact will be. An effective disaster mitigation strategy must promote the application of appropriate scientific tools for planning and management that raises public awareness of the potential hazards and promotes public participation in mitigating their impact. Thus public education about the hazards and instructions of what to do when they happen, are key elements for preparedness and disaster mitigation.

The potential of social and economic losses due to a catastrophic environmental or man-made hazard becomes greater – particularly near densely populated sites or cities. A disaster may have a heavy impact on the regional infrastructure, which requires the taking of immediate and efficient actions to avoid the enhancement of a crisis situation and to ensure mitigation of damage as well as of potential losses of human lives. Particularly vulnerable because of continuing development and growth, are the oil-producing areas of Saudi Arabia along the Gulf. Because of growth and development, similarly vulnerable is the port city of Taif on the Red Sea, as well as the industrial cities of Jubail and Yanbu.

Proper mitigation of the impact of a disastrous event will depend primarily on available information to officials for quick and proper assessment of the situation and for the public to respond quickly to any warnings, which may be issued by local and national authorities. For a warning system to function effectively and for crisis management to be effective, information should be available in advance about the potential impact that each type of disaster may have, as well as maps showing where maximum damages could be expected due to unfavourable, local site conditions. The better a pre-existing reference database of an area at risk is outlined, the better a crisis-management team can react.

Therefore information of geodynamic or other processes is a basic need for the long-term safety of cities, settlements, infrastructure, industrial facilities and extended lifelines. The assessment of a hazard and of potential hazard-prone areas is fundamental for planning purposes and for risk preparedness. Areas at particular risk include networks, buildings, production, extracting and processing plants and non-electronic data records (Federal Ministry of the Interior, 2005). Also into consideration should be taken the technical interdependencies between infrastructures and the potential for initiating cascading effects of failure, loss of service and social disruption.

Needed Improvements in Disaster Risk Assessment Techniques, Management Tools and Strategies

To strengthen the economic and societal resilience of Saudi Arabia to potential disasters and to improve preparedness, prevention and mitigation, more appropriate risk assessment techniques must be adapted as well as new management tools and strategies. A first effort should be the identification of a potential hazard and of an area's vulnerability – the latter defined as "the condition determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards" (UN/ISDR, 2004).

Remote sensing and GIS techniques can also help contribute to a systematic and standardized inventory of areas in Saudi Arabia that are more susceptible to environmental, natural or man-made hazards. Aggregate occurrence of contributing "negative" factors obtained by such means may help evaluate a potential hazard's damage intensity for any given location. This information can be integrated into disaster preparedness and mitigation measurements. Therefore, Saudi Arabia's efforts in developing strategies to mitigate the impacts of disasters and to manage future crises could benefit greatly by the adaptation or expansion of remote sensing and GIS techniques in assessing natural and man-made disaster vulnerabilities and to manage effectively future crises.

An important aspect for the vulnerability assessment of a community and of the projected damage loss estimation is the almost actual inventory of land use and infrastructure (such as, railroads, roads, river embankments, bridges, etc.), of industrial facilities and of the structure of settlements and cities (considering age, structure and buildings' function). Resources for such Remote Sensing assessment can include GIS techniques and open-source tools as OpenStreetMap, or Google Earth. Also evaluations of RapidEye satellite imageries, ESRI base maps and further Web-tools may be used (Theilen-Willige & Pararas-Carayannis, 2009; Taubenböck et al., 2008; 2011). Airborne and space-borne remote sensing systems and image analysis techniques have been also developed to an extent where civil and commercial earth observation (EO) instruments can contribute significantly to supporting the management of major technical and natural disasters as well as humanitarian crisis situations. A standardized, reference data base of industrial facilities and of critical infrastructures with environmental impact in case of accident should be available, in order to improve the preparedness and mitigation management.

Adaptation strategies must be developed which use the Geographic Information Systems (GIS), together with remote sensing data, to help with the analysis and presentation of information, especially required for the increasing geo-hazards. Such techniques were used to designate flooding risks in Myanmar (Theilen-Willige & Pararas-Carayannis, 2009) and in assessing hazards in the Marmara Sea region (Pararas-Carayannis et al., 2010).

The ability to undertake the assessment, monitoring and modelling can be improved to a considerable extent through the current advances in remote sensing and GIS technology. Geographic Information Systems (GIS) provide the appropriate platform for the registration and management of information. Causal or critical environmental factors influencing the disposition of settlements, industrial and infrastructural facilities to be affected by natural hazards and the potential damage intensity can be analysed interactively in a GIS database. The interactions and dependencies between different causal factors can be visualized and weighted step by step in this GIS environment. Objective is the detection of areas more susceptible to hazards and, thus, as consequence, the vulnerability assessments according to a standardized, systematic and clearly arranged approach that can be used in any area (Theilen-Willige & Pararas-Carayannis, 2009).

The elaboration of a database for factors of local site conditions, which influence the damage potential, could become in the future part of a comprehensive management system. Local, geomorphologic site conditions play an important role as well when considering flooding susceptibilities. Local morphometric properties that can be derived from digital elevation data and evaluations of aerial and satellite data from any coastal area according to the same approach in a GIS influence the susceptibility to flooding. Whenever inundation events happen in coastal areas due to flash floods, storm surge or tsunami waves, the morphometric settings determine the susceptibility to be affected by inundations to a great extent.

CONCLUSIONS

There is an urgent need to address trends and the means by which marine and terrestrial resources in Saudi Arabia can be sustained and adverse trends reversed or mitigated. While disaster awareness and preparedness are two important parameters that can help mitigate the impact of future disasters in the area, as this paper points out, more comprehensive strategies must be adopted to offset increasing threats. Since different areas in Saudi Arabia are vulnerable to various disasters, each community must assess its own vulnerability and risks and develop specific strategies. Effective disaster mitigation requires the assumption of greater responsibility by individuals, groups, organizations and government agencies.

REFERENCES

Alamri, Y. A. 2010. Emergency Management in Saudi Arabia: Past, Present and Future. Un. Of Christchurch report, New Zealand.

Federal Ministry of the Interior (2005): Protection of Critical Infrastructures – Baseline Protection Concept, Recommendation for Companies. http://www.bmi.bund.de

Jordan B. R., 2008. Tsunamis of the Arabian Penisnula – a Guide of Historic Events. Science of Tsunami Hazards, Vol. 27, No. 1, page 31 (2008)

Fritz H. M., Blount C, D., Albusaidi F. B, Hamoud A., Al-Harthy M, 2010. Cyclone Gonu storm surge in Oman. Estuarine, Coastal and Shelf Science Volume 86, Issue 1, 1 January 2010, Pages 102–106

Pararas-Carayannis, G., 1975, *"Verification Study of a Bathystrophic Storm Surge Model*", U.S. Army, Corps of Engineers - Coastal Engineering Research Center, Washington, D.C., Technical Memo. No. 50, May 1975.

Pararas-Carayannis, G., 1986, 1988. "*Risk Assessment of the Tsunami Hazard",* Proceedings of the International Symposium on Natural and Man-Made Hazards, Rimouski, Canada, August 3-9, 1986.In Natural and Man-Made Hazards, D. Reidal, Netherlands, pp.171-181, 1988.

Pararas-Carayannis, G., 2003, "*Climate Change, Natural and Man-Made Disasters - Assessment of Risks, Preparedness and Mitigation",* 30th Pacem in Maribus, Kiev, Ukraine, October 26-30, 2003
http://drgeorgepc.com/ClimateChange.html

Pararas-Carayannis, G., 2003, Near and far-field effects of tsunamis generated by the paroxysmal eruptions, explosions, caldera collapses, massive slope failures of the Krakatau Volcano in Indonesia on August 26-27, 1883, Science of Tsunami Hazards, v. 21, n. 4., p. 191-201.

Pararas-Carayannis, G., 2006. The Potential of Tsunami Generation Along the Makran Subduction Zone in the Northern Arabian Sea - Case Study: The Earthquake of November 28, 1945, Science of Tsunami Hazards, Vol. 24, No. 5, pages 358-384 (2006)

Pararas-Carayannis, G., (2006a), "*Disaster Risk Assessment - Overview of Basic Principles and Methodology"* "Natural Disaster Risks", Risk Journal pp. 17-73, March 2006.

Pararas-Carayannis G., Theilen-Willige B., and Wenzel Helmut, 2010. LOCAL SITE CONDITIONS INFLUENCING EARTHQUAKE INTENSITIES AND SECONDARY COLLATERAL IMPACTS IN THE SEA OF MARMARA REGION - Application of Standardized Remote Sensing and GIS-Methods in Detecting Potentially Vulnerable Areas to Earthquakes, Tsunamis and Other Hazards. Fifth International Tsunami Symposium of Tsunami Society International, Toronto, Canada 2010

RapidEye AG (2011). Satellite Imagery Product Specifications, Version 3.2. RapidEye AG, Molkenmarkt 30, D-14776 Brandenburg an der Havel, Germany, www.rapideye.de

Taubenböck, H., Post, J., Roth, A., Zosseder, K., Strunz, G., and Dech, S. (2008): A conceptual vulnerability and risk framework as outline to identify capabilities of remote sensing, Nat. Hazards Earth Syst. Sci., **8**, 409–420, doi:10.5194/nhess-8-409-2008, 2008.

Taubenböck, H., Wurm, M., Netzband, M., Zwenzner, H., Roth, A., Rahman, A., and Dech, S.: Flood risks in urbanized areas multi-sensoral approaches using remotely sensed data for risk assessment, Nat. Hazards Earth Syst. Sci., 11, 431–444, doi:10.5194/nhess-11-431-2011, 2011. http://www.nat-hazards-earth-syst-sci.net/11/431/2011/nhess-11-431-2011.html

Theilen-Willige B. & Pararas-Carayannis G., 2009. Natural hazard assessment of SW Myanmar – A contribution of remote sensing and GIS methods in the detection of areas vulnerable to earthquakes and tsunami/cyclone flooding. Science of Tsunami Hazards, Vol 28. N. 2, 2009.

UN/ISDR (United Nations/International Strategy for Disaster Reduction) 2004: Living with Risk: A Global Review of Disaster Reduction Initiatives, United Nations International Strategy for Disaster Reduction, UN Publications, Geneva, Switzerland.