to increase resilience and thus ensure sustainable urban development. To this end, it is important to define the natural hazards facing Arab cities and the range of existing and emerging risks they will have to confront in order to ensure resilient sustainable development and prosperity in the future.

03

Hazards, exposure and risks

3.1 Hazard exposure of the Arab states: general overview

This chapter provides a general overview of the hazard profile of the region and further explores two main hazards: hydrometeorological and geophysical. It also highlights some vulnerabilities and risks that may be expected in relation to the main hazards at both national and urban levels.

There is very little disaster-related data available for the region. The occurrence and impact of disasters in terms of losses and damage has also been largely underreported.[1] Reliance to date has been on two databases: the Emergency Events Database (EM-DAT)[2] and the multi-stakeholder initiative on Disaster Inventory Management System – DesInventar.[3] The Global Disaster Loss Collection Initiative rolled-out by UNISDR in collaboration with UNDP has helped ten Arab countries to implement their own national disaster damage and loss databases. These countries are Comoros, Djibouti, Egypt, Jordan, Lebanon, Morocco, Palestine, Syria, Tunisia and Yemen.

Despite some discrepancies between the data sets available in both databases, (while EM-DAT has information about almost all the countries in the region, the DesInventar data include more indicators) and pros and cons of each of them, these databases help to understand the main hazards faced across the region. Table 7 below provides an overview of the number and the type of disasters affecting each country, based on the data sets from EM-DAT and the national disaster damage and loss databases.

Table 7
Overview of number and types of disaster events per country

Number of events in 22 Arab countries (30 year period from 1982 to 2011)

Countries	Earthquakes	Forest Fires	Landslides	Floods	Cyclones	Flash Floods	Other	Total
Comoros	0	0	0	2	4	0	7	13
Djibouti	10	0	7	110	0	0	233	360
Egypt	12	0	0	1	0	1	42	56
Jordan	16	26	7	94	0	49	401	593
Lebanon	35	1 363	64	91	1	156	697	2 407
Morocco	6	624	0	66	0	0	10	706
Palestine	3	5	1	66	0	0	262	337
Syria	0	3 176	13	93	2	8	4 003	7 295
Tunisia	17	77	4	336	1	0	1 235	1 670
Yemen	70	0	137	112	3	42	1 098	1 462
Number of events in 22 Arab countries (30 year period from 1982 to 2011), EM-DAT								
Algeria	12	2	1	0	0	5	38	58
Bahrain	0	0	0	0	0	0	0	0
Emirates	0	0	0	0	0	0	0	0
Iraq	1	0	0	0	0	4	3	8
Kuwait	0	0	0	0	0	1	0	1
Libya	0	0	0	1	0	0	0	1
Mauritania	0	0	0	6	0	1	15	22
Oman	0	0	0	0	4	0	1	5
Qatar	0	0	0	0	0	0	0	0
Saudi Arabia	0	0	0	0	0	1	11	12
Somalia	0	0	0	0	1	7	31	40
Sudan	0	0	0	13	0	3	26	42

Source: EM-DAT

FOOTNOTES

1 Ezzine 2015, pp. 38, 40.

2 http://www.emdat.be.

3 DesInventar Official Website [https://www.desinventar.org/en/]. DesInventar Sendai [http://www.desinventar.net/].

An analysis of the nature of disasters in Arab states, based on the information from the national databases, reveals that, in the period 1982 to 2011, the region experienced 14,477 hydrometeorological and 422 geophysical events (i.e., 97 per cent compared to 3 per cent).[4] Thus, since 1982, hydrometeorological events have been much more frequent and destructive than geophysical events, although the geophysical hazards are more concentrated in space and have longer return period. Flooding is the most common natural hazard experienced in the region, followed by droughts, storms and fires.

The following sections offer more detailed analysis of the two main hazards in the Arab region: hydrometeorological and geophysical events.

This section presents the main results of recent regional hydrometeorological modelling projections from a climate change perspective, and the risks it poses to Arab states and Arab cities in general. It further highlights some important vulnerabilities to hydrometeorological hazards in the main Arab cities.

3.2 Hazard profile: hydrometeoro-logical hazards

3.2.1 Climate and hydrometeorological hazards

Climate change induced temperature increases, rainfall variability, droughts, tropical storms and flooding have been already observed across the Arab region.[5] Transition to increased aridity with recurrent drought spells have been experienced in the region since the mid-twentieth century. The droughts have worsened over the last decades especially in Morocco, Syria, Somalia and Djibouti.

According to UNISDR, "climate change has an impact on the frequency and intensity of extreme weather events. High variations of rainfall with an increase in flood events impact the Arab region."[6] In general, hydrometeorological disaster scenarios are facing an upward trend since the second half of last century. Flood mortality risk has increased. The rate of flash flooding occurrence in the region has also doubled over the last two decades.[7]

The recurrence of droughts is projected to increase further in the medium- and long-term future.[8] From 2006 to 2011, the region suffered some of its worst droughts on record, contributing to famine in Somalia, the widespread loss of millions of farm-based livelihoods in Syria, Iraq and Yemen, and the displacement of millions across the region.[9]

FOOTNOTES

[4] Ezzine 2015, p. 42.
[5] Osman-Elasha 2010.
[6] UNISDR 2013.
[7] UNESCO 2010.
[8] Erian 2013.
[9] Kelley et al. 2015.

Sea level rise (SLR) has the potential to affect two to four million vulnerable farmers of the Nile Delta in Egypt. Moreover, SLR is predicted to affect other major cities in the region including Alexandria, Algiers and Tunis. In addition, the rate of extreme weather events, including tropical cyclones, coastal erosion, sand storms, strong winds, heat and cold waves, is increasing across Arab countries. For instance, an estimated 700,000 persons were internally displaced as a result of climate-induced severe flooding which affected the low-lying Wadi Hadramout and Al-Mahra in Yemen in 2008.[10]

The following section highlights more about the impact of climate change on the growth of disaster risks in the region.

3.2.1a Regional climate

As estimated by the UN after the secession of South Sudan,[11] the Arab region covers 13.15 million km^2 (more than 2.5 times the size of Western Europe) and stretches from the Atlantic Ocean to the Zagros Mountains in South-West Asia. The region extends into both the African and Asian continents, with 72 per cent of the area (9,975,508 km^2), and 67 per cent of the inhabitants (260,718,000) in Africa. The population density, however, is a little higher in the Asian Arab countries than in the African.[12]

The climate of Arab countries ranges from Mediterranean, with warm and dry summers and wet rainy winters, through subtropical zones, with variable amounts of summer monsoon rains, to deserts with virtually no rain. During the winter, variability in the North Atlantic Oscillation (NAO) influences storm tracks; annual variations in rainfall in Western and Central North Africa (the Maghreb), most of the Mashreq and the Arabian Peninsula are largely governed by this NAO effect. The eastern part of the region (the Mashreq, the Gulf, and Centre regions) – where it rains mainly during the winter – is almost without rainfall in summer. The south-eastern area of the region (Yemen and Oman) is influenced by the Indian monsoon system, which is largely controlled by the position of the Inter-Tropical Convergence Zone (ITCZ)[13] and therefore has a secondary summer rainfall maximum. Occasionally, these countries also experience serious consequences due to tropical cyclones. Environmental challenges in the Arab region include water scarcity, with the lowest fresh water resource endowment in the world; very low and variable precipitation; and excessive exposure to extreme events, including drought and desertification.

FOOTNOTES

[10] Yemen 2015.

[11] http://data.un.org/Search.aspx?q=arab+world+surface+area. Accessed 13 December 2016.

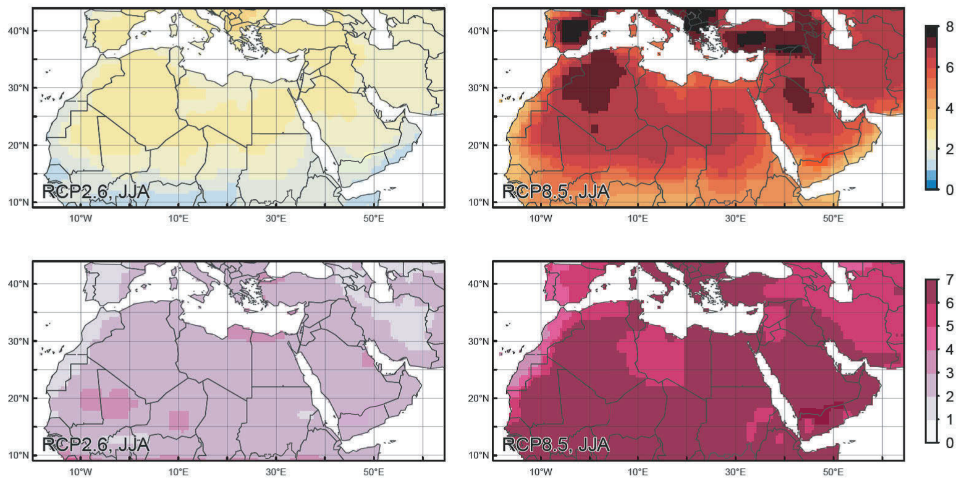
[12] Al-Madhari and Elberier 1996.

[13] The Inter-Tropical Convergence Zone is an equatorial zonal belt of low pressure near the equator where the northeast trade winds meet the southeast trade winds. As these winds converge, moist air is forced upward, resulting in a band of heavy rainfall. This band moves seasonally (IPCC Glossary: https://www.ipcc.ch/publications_and_data/ar4/wg1/en/annexessglossary-e-o.html).

3.2.1b Regional patterns of climate change: expected temperature change and heat extremes in the Arab region

Warming of 0.2°C per decade has been observed in the region since 1961–1990, and since then, the warming has been at an even faster rate. Geographically, the strongest warming is projected to take place close to the Mediterranean coast. Here, as well as in the hinterland of Algeria, Libya and large parts of Egypt, warming by 3°C (in a 2°C world) is projected by the end of the century. In a 4°C world, the probability density function of monthly temperatures (associated with the year-to-year variability of monthly temperatures) shifts by six standard deviations toward warmer conditions across all regions, from the Sahara to the Arabian Peninsula to the eastern Mediterranean coast. Such a large shift implies that summer temperatures here will move to a new climatic regime by the end of the twenty-first century. Such a dramatic change would be avoided in a 2°C world; (World Bank 2014, p. 122). Even then, however, a substantial shift is expected to take place: the mean summer temperatures are expected to be up to 8°C warmer in parts of Algeria, Saudi Arabia and Iraq by the end of the century (Figure 7).

Figure 7
Multi-model mean temperature anomaly for Representation Concentration Pathway (RCP) 2.6 (2°C world, left) and RCP 8.5 (4°C world, right) for the months of June-July-August (JJA) in the Middle East and North African region.



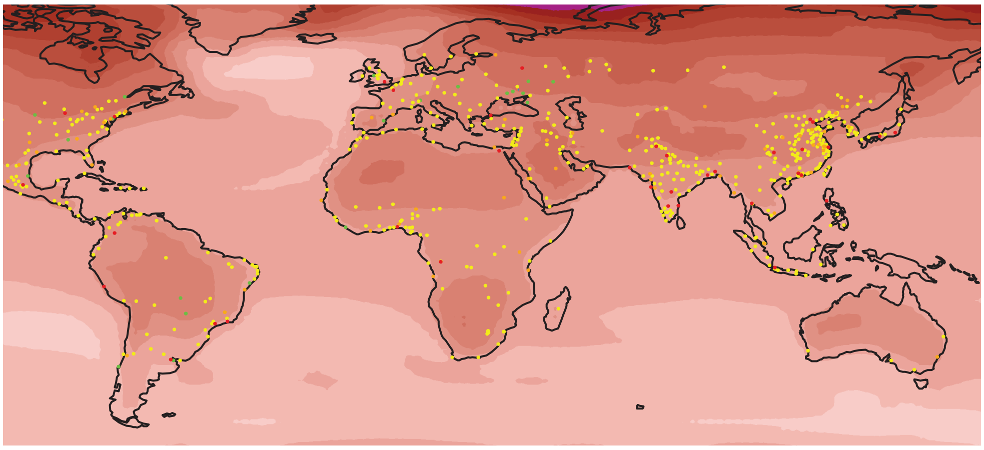
*Temperature anomalies in degrees Celsius (top row) are averaged over the time period 2071–2099 relative to 1951–1980, and normalized by the local standard deviation (bottom row).

Source: World Bank 2014, p.121.

3.2.1c Urban temperature in Arab countries

With the increase in temperature, the frequency of hot days and warm spells will increase and exacerbate urban heat island (UHI) effects. Figure 8 shows that the population living in the largest urban agglomerations (based on their 2025 populations) will be exposed to a minimum 2°C temperature rise over pre-industrial levels, excluding UHI effects. Climate change will modify UHI effects, causing a mean rise of 3.5°C in some cities, resulting in a combined rise of more than 5°C. Peak seasonal temperatures could be even higher. Recent studies using physically-based models (McCarthy et al. 2010, Früh et al. 2011, Oleson 2012) show mixed results, with reductions in UHI effects in many areas of the world and increases elsewhere in response to climate change.[14]

Figure 8
Large urban agglomerations 2025 with projected climate change for the mid-twenty-first century using RCP 8.5 scenario



°C

0.19–0.5	1.51–2.0	3.01–3.5	4.51–5.0	6.01–8.0
0.51–1.0	2.01–2.5	3.51–4.0	5.01–5.5	
1.01–1.5	2.51–3.0	4.01–4.5	5.51–6.0	

City population 2025
- 0.75–1 million
- 1–5 million
- 5–10 million
- 10 million or more

Source: IPCC 2014

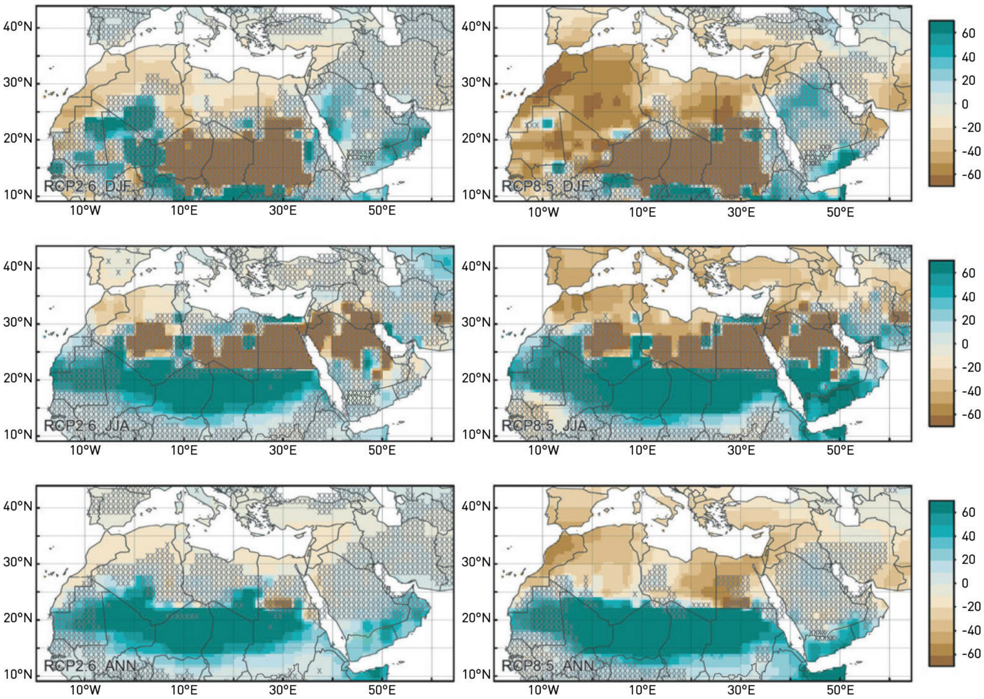
3.2.1d Regional patterns of climate change: precipitation trends in Arab region

The multi-model percentage changes for the annual mean precipitation (averaged over 2046–2065) are:

- 10 to +24 per cent for mid-twenty-first century of RCP 2.6;
- 9 to +22 per cent for late twenty-first century of RCP 2.6;
- 19 to +57 per cent for mid-twenty-first century of RCP 8.5; and
- 34 to +112 per cent for late twenty-first century of RCP 8.5 (figure 9).

FOOTNOTES
[14] Climate Change 2014: Impacts, Adaptation, and Vulnerability, IPCC http://www.ipcc.ch/report/ar5/wg2/

Figure 9
Multi-model of the mean percentage change in winter (DJF, top), summer (JJA, middle) and annual (bottom) precipitation for RCP 2.6 (2°C world, left) and RCP 8.5 (4°C world, right) for the Middle East and North Africa by 2071–2099 relative to 1951–1980



Source: World Bank 2014, p. 124

Trends in aridity lead to changes in annual water discharge that can be taken as a first-order approximation of the water resources available to humans. Profound changes in river run-off are already evident for a 2°C world. Although the Arab region occupies 10 per cent of the planet, it owns less than one per cent of the world's fresh water resources, with available water resources of less than 1,000 m^3 per capita per year in all Arab states except Iraq, Syria and Lebanon.

Figure 10 shows the percentage change in the aridity index (AI).[15] AI is designed to identify regions with an ongoing precipitation deficit[16] and is a standardized measure of water demand. "*Changes in the AI are primarily driven by changes in precipitation causing an increase in the AI (wetter conditions) south of 25° N (i.e., the Sahel and the most southern part of the Arabian Peninsula) and a decrease in AI (drier conditions) north of 25° N. The relative increase in AI values in the southern region is similar to the relative increase in annual mean precipitation (about 50 per cent wetter conditions), as the change in potential evapotranspiration is small. Note that this relative increase in AI south of 25° N is superimposed on an already very low AI value, which results in AI values still classified as arid.*"[17]

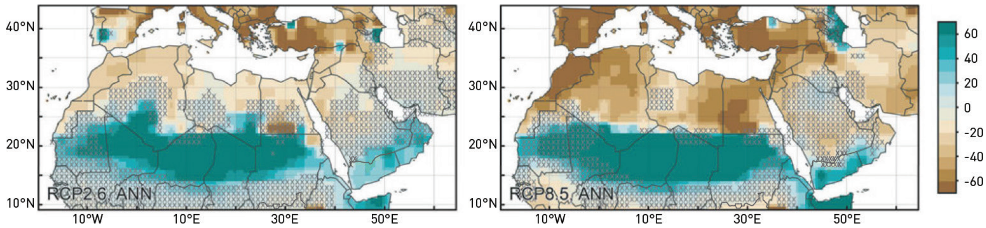
FOOTNOTES

[15] AI is calculated as the total annual precipitation divided by the annual potential evapotranspiration (World Bank 2014, p. 126).

[16] Ibid, citing Zomer et al. 2008.

[17] Ibid.

Figure 10
Multi-model mean of the percentage change in the aridity index under RCP 2.6 (2°C world, left) and RCP 8.5 (4°C world, right) for the Middle East and North Africa by 2071–2099 relative to 1951–1980.



Source: World Bank 2014, p. 126

Climate change projections show stark differences in the effects across the region. Although runoff in North Africa and the eastern Mediterranean (including the headwaters of the Euphrates and the Tigris) is expected to drop by up to 50 per cent, Southern Saudi Arabia and East Africa (including the headwaters of the Nile) will experience increases in runoff by up to 50 per cent. Consequently, climate change is projected to reduce water supplies in the northern and western parts of the Arab region and to increase the supply in Egypt and the southern part of the region.

Eastern Mediterranean and the Arabian Peninsula are projected to become drier, especially in the rainy season. Studies on *"the projected change in the monthly mean rainfall over the eastern Mediterranean [...] found a significant decrease in rainfall, on the order of 40 per cent, at the peak of the rainy season (December and January) over the Mashreq. This change is due to a reduction in both the frequency and duration of rainy events. Before and after the rainy season, the situation is less clear, with some areas projected to get wetter and others drier."*[18]

3.2.2 Risks to urban systems

Due to climate change and the resulting increase in intensity, frequency and duration of extreme events, stress upon environment *"is becoming important in fragile ecosystems and drylands with limited natural resources as in the Arab region. On the one hand, demographic growth and high per capita consumption have increased the demand for environmental resources. On the other hand, environmental depletion and degradation have reduced both the quantity and the quality of renewable resources. In addition to this supply/demand-induced dynamic, the unequal distribution of environmental resources must be considered. These combined trends would create a serious deficit of environmental resources in poor countries and fuel pre-existing grievances such as ethnic, religious or economic marginalization."*[19]

Changing climate patterns and the increased risk of hydrometeorological disasters in the region, strain the ability of Arab States and cities particularly, to provide sufficient water for people, the economy and ecosystems. "Current projections show that by the year 2025 the water supply in the Arab region will be only 15 per cent of what it was in 1960."[20] Sustainable urban development in the region, therefore, is very much about water scarcity and the relationship between water and other economic sectors: agriculture, energy,

FOOTNOTES
[18] World Bank 2012, p. 60, citing Black 2009.
[19] Erian et al. 2014, p. 32.

health, ecosystem and security. For instance, Yemen has all the chances to become the first country to run out of water.[21]

Figure 11 demonstrates the general projected impact of climate change on key sectors in the Arab region.[22] It is also important to highlight the interdependencies and correlations between various risks across sectors. In the Arab region the nexus between water-food security and social unrest is becoming more entwined, with potential destabilizing effects on some countries. The direct and indirect impact of hydrometeorological hazards can potentially trigger a wide range of different risks for urban systems.

Direct impact

- Changes in precipitation patterns and water cycles will increase the existing problems of water supply and water quality.
- Cities like Alexandria, located in deltas, are more likely to be affected by coastal flooding as they may have a lower elevation, suffer natural subsidence to a greater or lesser extent and, in some cases, receive more water discharge from melting snow-fed rivers (Basra).
- Climate change is expected to increase environment-related diseases. Warmer and/or wetter breeding seasons will provide ideal conditions for the proliferation of mosquito-borne diseases, such as puddles where malaria-carrying mosquitoes breed.
- Lack of sanitation and potable water will increase water contamination and food-borne diseases like cholera, typhoid, diarrhoea, hepatitis and gastroenteritis. Warmer cities will also lead to an increase in respiratory diseases due to pollution, whose effects are reinforced by higher temperatures.
- Warming will be felt more in cities because of the urban heat island (UHI) effect that makes cities warmer than their surroundings by 2°C to 6°C due to the modification of the land surface and waste heat produced by high energy use. Heat waves that can kill hundreds of people may become more frequent and intense. The increase of UHI will cause heat-related health problems[23] and, possibly, increased air pollution.[24] It is expected that energy demands will be increased for warm season cooling.[25] UHI in the Arab region and its effect on the population require additional studies.
- Storms, floods and coastal/delta flooding that are expected to be more frequent will put infrastructure at greater risk. This includes transportation (i.e., roads, railways, bridges, ports and airports) and communication networks, water supply, sewage, gas pipelines, drainage, flood and coastal defence systems, power and telecommunication infrastructure, industrial units and processing plants. In terms of buildings, informal and traditional housing are the most vulnerable to storms and floods.[26]

FOOTNOTES

[20] UNDP 2013a, p. IV.

[21] http://science.time.com/2010/12/14/what-if-yemen-is-first-country-to-run-out-of-water/.

[22] World Bank 2014, p. xxxiv.

[23] IPCC 2014a, p. 554, citing Hajat et al 2010.

[24] Ibid, citing Campbell-Lendrum and Corvalán 2007.

[25] Ibid, citing Lemonsu et al. 2013.

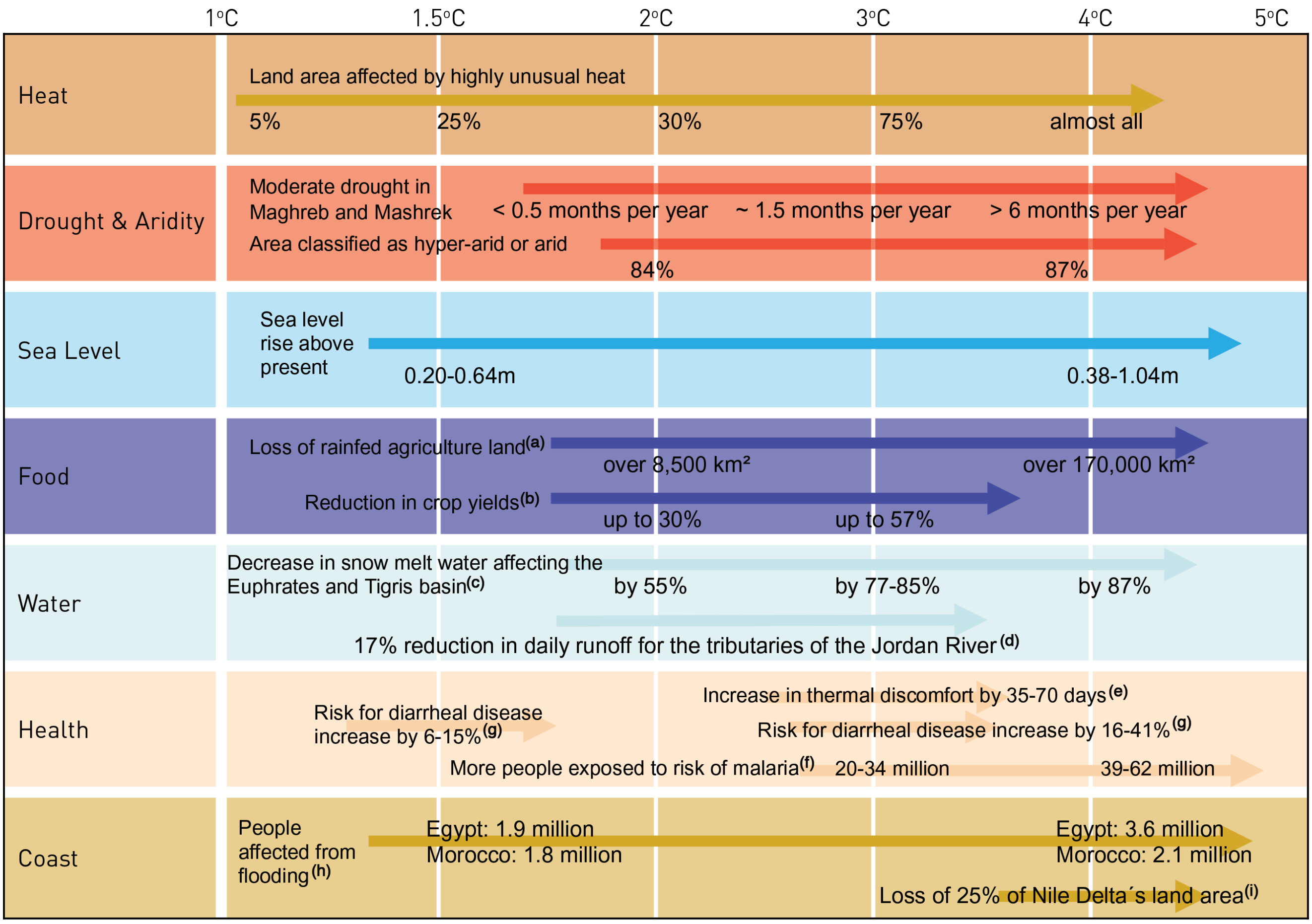
[26] http://base.d-p-h.info/pt/fiches/dph/fiche-dph-8632.html

Indirect impact

- "Continued urban expansion into hazard-prone areas means that a growing proportion of urban populations will be at risk of climate-related extreme events and rising food prices, and thus of increasing poverty levels among urban groups."[27] In this context, "Mauritania and Yemen stand out as the most food-insecure countries."[28]
- In combination with non-climatic pressures, a decline in rural livelihood options could trigger further urban migration, potentially exacerbating urban vulnerability and intensifying the potential for conflict. Migrants are generally the most vulnerable group in any city. With no access to the city's livelihood network and lacking skill sets to enable them to thrive, these people live in illegal slums with no access to basic amenities. This group is thus highly vulnerable to a variety of risks arising from living in such hazardous conditions (e.g., environmental health risks due to poor sanitation and inadequate water supply, little or no drainage or solid waste disposal services, air and water pollution, as well as the constant threat of eviction).
- Risk of food insecurity and the breakdown of food systems due to warming, drought and flooding, as well as precipitation variability and extremes, most particularly affecting poorer populations in urban and rural settings, as indicated by IPCC (2014a).
- Heat waves could have a major impact on the economy. Episodes of heat cramps, heat exhaustion and heat stroke would affect the population, primarily the large poorer section of society. As the immune system weakens due to heat stress, susceptibility to disease would further increase. The health care expenditure incurred by individuals as a result would escalate, leading to greater stress. This vicious cycle would therefore lead to a reduction in human resources. As temperatures increase, the number of days available for heavy work, like construction, will decrease which may also have a negative impact on economic growth.
- Climate change may act as a threat multiplier to the security situation in the region by bringing additional pressures on already scarce resources and by reinforcing pre-existing threats related to migration following forced displacement.[29]

FOOTNOTES

[27] World Bank 2014, p. xxii, box 2.
[28] Harrigan 2014, p. 35.
[29] World Bank 2014, pp. xxvi, 116, 157.



Source: World Bank 2014, p. xxxiv

Figure 11
Projected impacts of climate change on key sectors in the Middle East and North Africa region

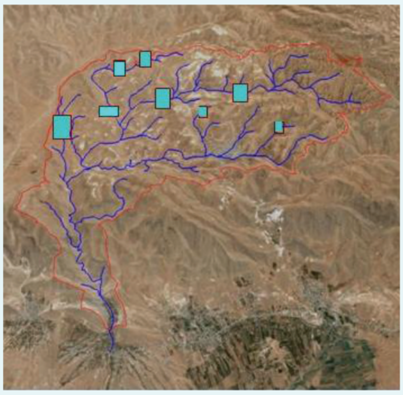
There are large differences among Arab urban centres to the extent to which their economies are dependent on climate-sensitive resources (including commercial agriculture, water and tourism). Cities in high-income countries (Gulf Cooperation Council) and many in middle-income countries, for example, have become relatively more resilient to extreme weather (and other possible catalysts for disasters) through a range of risk response measures that have already been put in place. There are many practices worth sharing across the region.

Box 2
Flood management measurements at Arsal, al-Fakeha and al-Qaa cities in Beqaa – Lebanon

Northern Beqaa urban areas, such as al-Fakeha and Ras Baalbek, are surrounded by a mountainous terrain that drains into these areas causing frequent flooding with the destruction of homes and roads. Major events have occurred in 1987, 1994 1999, 2001, 2004 and 2007.

The vegetation cover in the vicinity of al-Fakeha city was increased in order to mitigate land degradation from water erosion and reduce the impact of flash floods on the city and the agricultural land located downstream of the watershed. Two different types of structures were built to reduce the volume of flood water before it reaches al-Fakeha city. Surface run-off was diverted into storage structures such as percolation ponds (hafir). Smaller dispersed structures were built to provide in situ retention of rainfall, such as stone contour bunds, stone walls, and check dams.

Author: Wadid Erian, Egypt



3.2.3 Special focus area: risk of drought in the main Arab cities

Climate change is likely to increase the frequency of meteorological droughts (aridity and the duration of dry periods), agricultural droughts (less soil moisture), and hydrological droughts (shortfalls in water supply) in presently dry regions by the end of the twenty-first century. Annual maximum wet-bulb temperature (TW_{max}) increases monotonically in different locations surrounding the Gulf. Thus, the severest values of annual TW_{max} occur in Kuwait and Al Ain, where the 60°C threshold will be frequently exceeded several times by the end of the century.[30] In these locations, 50°C events will become normal during July, August and September. Rainfall is predicted to decline in parts of the region by 20 to 40 per cent in a 2°C world and by up to 60 per cent in a 4°C world. Such a combination creates all the necessary preconditions for drought risk in the region, with widespread consequences for various systems.

FOOTNOTES

[30] Pal and Eltahir 2015, p. 2 (198), considering both dry-bulb temperature (T) and wet-bulb temperature (TW), specifically their daily maxima averages over 6 hours [which is considered the maximum duration fit humans can survive at 35°C] denoted by Tmax and TWmax respectively. (Ibid. p. 1[197])..

Table 8
SPEI change over 50 years in main Arab cities by population

Table 8 shows the ranking of Arab cities according to the Standardized Precipitation-Evapotranspiration Index (SPEI)[31] with the change difference that took place between two periods: (Average for the years 2001-2010) and (Average for the years 1961-1970).

Country	City Name	Current Total Population	Average SPEI in different decades calculated for all year					SPEI change in 50 years	SPEI change in Summer months (July August September) for 50 years
			y617 0	y7180	y8190	y91_00	y00_10	(2001 to 2010) minus (1961 to 1970)	
Algeria	In Salah	32 518	1.50	2.50	0.75	-0.70	-3.49	-4.99	-3.9
Libya	Ghadames	10 000	1.25	1.50	0.75	-0.30	-3.49	-4.74	-3.5
Sudan	Wadi Halfa	15 725	1.25	1.00	1.50	0.25	-3.49	-4.74	-3.2
Saudi Arabia	Jeddah	3 400 000	1.25	0.25	0.50	-0.20	-3.49	-4.74	-3
Saudi Arabia	Makkah	1 675 368	1.25	-0.10	0.75	-0.20	-3.49	-4.74	-2.8
Egypt	Aswan	290 327	1.25	0.50	1.50	0.75	-3.49	-4.74	-2.5
Libya	Murzuq	12 746	0.50	1.50	0.75	-0.30	-3.49	-3.99	-2.2
Sudan	Khartoum	6 527 500	1.25	0.50	-0.60	0.25	-3.49	-4.74	-2
Sudan	Omdurman	2 395 159	1.25	0.50	-0.60	0.25	-3.49	-4.74	-2
Algeria	Tindouf	45 966	0.75	1.50	-0.30	-0.10	-3.49	-4.24	-1.9
Sudan	Bur Sudan	489 725	1.25	0.25	-0.60	0.25	-3.49	-4.74	-1.8
Iraq	Baghdad	7 216 040	0.50	1.00	0.50	-0.60	-3.49	-3.99	-1.4
Saudi Arabia	Ar Riyad	5 700 000	0.25	0.25	0.50	0.25	-3.49	-3.74	-1.3
UAE	Abu Dhabi	1 500 000	1.25	-1.94	0.25	-0.50	-0.40	-1.65	-1.3
Kuwait	Kuwait City	1 375 000	0.25	1.00	-0.50	-0.20	-3.49	-3.74	-1.2
Algeria	Oran	759 645	0.75	1.50	-0.20	-0.70	-0.60	-1.35	-1.2
Libya	Banghazi	435 886	0.50	0.25	0.25	0.50	-3.49	-3.99	-1.2
Iraq	Basra	2 750 000	0.25	1.00	-0.30	0.25	-3.49	-3.74	-1.1
Libya	Tripoli	1 126 000	0.25	1.00	0.25	-0.50	-3.49	-3.74	-1
Tunisia	Sfax	330 440	0.25	1.00	0.25	-0.30	-3.49	-3.74	-1
Yemen	Aden	760 923	0.75	-1.94	1.50	0.25	-0.60	-1.35	-1.1
Qatar	Doha	900 545	0.50	-0.40	-0.20	-0.10	-0.50	-1.00	-1
Yemen	Sanaa	1 937 451	1.25	-1.94	-0.30	0.25	0.25	-1.00	-0.9
Morocco	Fes	1 112 000	0.75	1.00	-0.60	-0.50	-0.50	-1.25	-0.9
Morocco	Marrakech	928 850	0.50	0.25	-0.10	0.25	-0.70	-1.20	-0.9
West Bank	Jerusalem	890 428	0.25	0.50	0.50	-0.10	-3.49	-3.74	-0.9
Egypt	El-Giza	3 628 062	-0.20	0.25	1.50	-0.10	-3.49	-3.29	-0.5
Somalia	Mogadishu	1 280 000	0.75	-0.50	0.25	-0.40	-0.20	-0.95	-0.9
Algeria	Tamanrasset	92 635	0.50	0.50	0.25	-2.00	-0.30	-0.80	-0.9
Saudi Arabia	Al Madinah	1 180 770	0.25	0.50	0.75	0.50	-0.70	-0.95	-0.8
Mauritania	Nouakchott	958 399	0.50	-0.30	-0.50	0.25	-0.50	-1.00	-0.7
Iraq	Mosul	1 500 000	0.50	0.50	0.25	-0.40	-0.50	-1.00	-0.7
Oman	Muscat	1 288 330	0.50	-1.94	0.25	0.50	-0.40	-0.90	-0.7
Jordan	Amman	4 000 000	0.25	0.75	0.25	-0.50	-0.60	-0.85	-0.7
Morocco	Casablanca	3 359 818	0.50	0.75	-0.50	-0.50	-0.20	-0.70	-0.7
Syria	Homs	652 609	0.50	0.50	-0.20	-0.50	-0.20	-0.70	-0.5
Syria	Damascus	1 711 000	0.25	0.50	0.25	-0.30	-0.40	-0.65	-0.5
Egypt	Cairo	10 230 350	-0.10	0.25	1.50	0.25	-0.70	-0.60	-0.5
Djibouti	Djibouti	623 891	0.25	-1.94	0.75	0.50	-0.30	-0.55	-0.5
Tunisia	Tunis	1 056 247	0.25	0.75	-0.30	-0.50	-0.30	-0.55	-0.5
Syria	Aleppo	2 132 100	0.25	0.25	0.25	-0.20	-0.40	-0.65	-0.4
Algeria	Algiers	3 574 000	0.25	1.50	-0.40	-0.60	-0.40	-0.65	-0.3
Lebanon	Tripoli	850 000	0.50	0.50	-0.20	-0.70	-0.10	-0.60	-0.3
Egypt	Alexandria	4 546 231	-0.30	0.50	0.75	-0.20	-0.60	-0.30	-0.2

FOOTNOTES

[31] The SPEI is a multi-scalar drought index based on climatic data. It can be used for determining the onset, duration and magnitude of drought conditions with respect to normal conditions in a variety of natural and managed systems such as crops, ecosystems, rivers, water resources, etc. More information is available at http://sac.csic.es/spei/index.html.

The results confirm that the major Arab cities can be classified into cities with extreme, moderate and slight drought (as an average for all months).

- Cities with **extreme drought**: Ain-Salah and Tindouf (Algeria); Ghadames, Murzuq, Benghazi and Tripoli (Libya); Wadi Halfa, Port Sudan, Khartoum and Omdurman (Sudan); Jeddah, Makkah and Riyadh (Saudi Arabia); Aswan and Giza (Egypt); Baghdad and Basra (Iraq); Kuwait City (Kuwait); Sfax (Tunisia); and Jerusalem (Palestine).
- Cities with **moderate drought**: Abu Dhabi (United Arab Emirates); Oran (Algeria); Marrakech and Fes (Morocco); and Aden (Yemen).
- Cities with **slight drought**: Doha (Qatar); Sanaa (Yemen); Nouakchott (Mauritania); Mosul (Iraq); Mogadishu (Somalia); Al Madinah (Saudi Arabia); Muscat (Oman); Amman (Jordan); Tamanrasset (Algeria); Casablanca (Morocco); Homs, Damascus and Aleppo (Syria); Algiers (Algeria); Alexandria and Cairo (Egypt); Beirut and Tripoli (Lebanon); Djibouti (Djibouti); Tunis (Tunisia); Rabat (Morocco); and El Obeid (Sudan).

The **most affected cities** during summer could be ranked as follows: Rabat, Tamanrasset, Doha, Casablanca, Mogadishu, Djibouti, Tunis, Sanaa, Oran, Asmara, Al Madinah, Cairo, Addis Ababa, Amman, Aden, Abu Dhabi, Ain-Salah, Muscat, Damascus, Marrakech, Ghadames, Fes, Homs, Nouakchott, Mosul, Wadi Halfa, Alexandria, Makkah, Aleppo, Jeddah, Murzuq, Aswan and Tripoli.

3.2.4 Special focus area 2: coastal zones

The coastal zone of the Arab region is 34,000 km long in total, more than half of which is inhabited. *"Most of the Arab cities and towns from Gulf, to Levant, to Egyptian Delta and North Africa are located along the Arabian Sea, Red Sea and on either side of the Mediterranean Sea. In North Africa over 70 per cent of Tunisian and Libyan population lives in cities along the coast. The Egyptian Delta, with almost 40 per cent of the total Egyptian population, is sandwiched between the Mediterranean and Red Seas. The coast of Lebanon is an extended sprawl of towns and cities, so is the Saudi Arabian coast on Red Sea. In the Arabian Sea, in addition to archipelago of Bahrain, all major urban centres of Kuwait, Oman, Saudi, Qatar and UAE lay on the seaside."*[32]

Coastal cities like Agadir, Alexandria, Algiers, Aqaba, Basra, Bosaso, Beirut, Casablanca, Djibouti, Jeddah, Tripoli and Tunis are international commercial hubs.

FOOTNOTES

[32] UNDP, Arab Cities Disaster Resilience Programme 2014-2017, available at: http://procurement-notices.undp.org/view_file.cfm?doc_id=54089. Accessed 18 January 2017.

Box 3
Coastal zones: the case of Egypt

Ninety per cent of the Egyptian population lives along the Nile Delta. Protection of coastal zones remains a priority issue for Egypt with about 15 per cent of the population residing on the country's Mediterranean and Red Sea coasts. Along the Mediterranean Sea coast are the governorates of Matrouh, Alexandria, Beheira, Kafr el-Sheikh, Dakahlia, Damietta, Port Said and North Sinai. The governorates of South Sinai, Suez and the Red Sea are located along the Red Sea coast.

An increase in sea level as a result of changing climate poses risks to the coastal population, infrastructure and environment. It is therefore of strategic importance for Egypt to build resilience against natural hazards while pursuing its developmental priorities. In order to further improve the understanding of vulnerabilities of major coastal cities, the Arab Academy of Science, Technology and Maritime Transport, in partnership with the World Bank (WB), is evaluating climate scenarios for Alexandria 2030.

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"All coastal cities in the Arab region remain especially vulnerable to multiple hazards associated with climate change; e.g., sea level rise, coastal inundation, salinization, etc."[33] The coastal areas of the Maghreb and Mashreq are vulnerable to earthquakes, flash flooding and tsunamis. Flood and cyclone-related urban disasters could lead to economic losses amounting to billions of dollars. Cyclone Gonu, for example, resulted in losses amounting to USD 4.2 billion, while flooding in Jeddah led to losses amounting to more than USD 1 billion. The potential impact could go as far as severe damage to urban housing, transport networks, motor traffic, ports, office buildings, educational institutions and drainage systems. "The World Bank estimates that climate change in the Arab region will expose 80-100 million people to water stress and 6-25 million people to coastal flooding by 2025."[34] The consequences could reach well beyond the confines of regional geography.

Box 4
Critical infrastructure: the case of the Strait of Hormuz

The narrow Strait of Hormuz* is considered one of the most, if not the most, strategic straits of water on the planet. Sixty per cent of the world's total oil exports is transported from Bahrain, Iran, Iraq, Kuwait, Qatar, Saudi Arabia and the UAE through the Strait of Hormuz alone.

The Strait of Hormuz is an exclave of Oman (Musandam governorate), strategically located on the north coast of Iran and the south coast of the UAE. The importance of the Strait of Hormuz is critical not only to the economy of the City of Hormuz, but also to the economy of other oil-producing countries in the region (the GCC countries) as well as

FOOTNOTES

[33] Ibid.

[34] Serageldin et al. 2016, p. 46.

the stability of the global economy at large.
Therefore, building resilience to disaster and climate risks is of the utmost importance in safeguarding the critical regional and global infrastructure.

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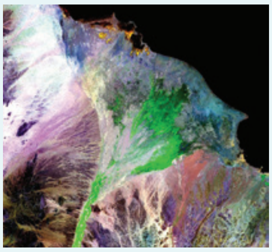
FOOTNOTES
*. http://www.heritageinstitute.com/zoroastrianism/hormozgan/peoplePlaces2.htm. Accessed 25 January 2017.

The coastal zones are, to varying extents, exposed to environmental pressures resulting from irrational development and pollution from several onshore and offshore sources, including industry, agriculture and urban development. These zones are also exposed to coastal erosion, Nile Delta inundation, seawater intrusion, soil and groundwater salinization, and similar environmental problems.

Box 5
Coastal zones: the case of Sudan's Tokar Delta



The Tokar Delta is located in the north-east of Sudan. The centre of the area is roughly about 90 km south of Suakin. It resembles an equilateral triangle with sides of about 70 km each. The climate in Tokar is arid; the average annual rainfall is 90 mm. It is hot and dry during the late spring, summer and early autumn months.

An important feature of the climate of Tokar Delta is the wind. These winds blow for several months in a southerly or south-westerly direction. They may blow constantly, often without let-up for several days, and cover the entire delta with a vast blanket of dust. Many people leave Tokar during such times. These haboob dust storms have beneficial effects. They bury or submerge in the sea the cotton debris that may harbour diseases. A less beneficial side effect of these winds is the shifting and reshaping of the dunes. The resulting erosion and soil blowing onto unprotected land has caused considerable damage.

The Baraka River and its main tributaries are the major streams in the area. It rises in the Eritrean highlands south of Keren and has two main branches. Baraka flood waters usually occur in a number of "flashes" and cover the delta during the months of July to September. The floods cut off the main road that links Tokar City with Suakin and the port of Sudan, fill the city streets with water and disrupt everyday activities. From the end of May until the beginning of October, both the dust storms and flooding bring to a halt all outdoor activities, except those that are absolutely necessary. The Government of Sudan is therefore working to relocate the town of Tokar Delta away from here. The government has started to build the new town of Tokar Delta beyond the confines of the area to which the population of the old city escapes to avoid the floods.

Wadid Erian

3.2.5 Main findings

(a) Climate change will significantly alter the ecologically important attributes of hydrologic regimes in rivers and wetlands, and exacerbate the impact of human water use in developed river basins, thus having a direct impact on water quality and availability for most cities, exerting pressure on fresh water supplies, sewage, the built environment and public health.
(b) The Arab region is a global hotspot for worsening extreme heat, drought, aridity and flash flood conditions.
  (b1) Projections indicate that in a 4°C world more than 90 per cent of summers will have unusually high heat extremes, compared to between 20-40 per cent of summers in a 2°C world.
  (b2) Oasis cities and hinterlands will be increasingly subjected to extreme heat, aridity and dust storms, which would lead to economic, environmental and public health problems.
  (b3) The eastern Mediterranean and Arabian Peninsula are projected to become drier, especially during the rainy season.
(c) Extreme heat, drought, aridity and flash floods will increase social vulnerability, instability, poverty, inequality and migration; all of which are becoming increasingly complex to manage.
(d) High density cities could bring efficiency gains and technological innovation while reducing resource and energy consumption.
(e) Many cities will become increasingly dependent on groundwater and desalinated water as a major source for potable water.
(f) Rapid urbanization and the growth of large cities has been accompanied by the development of highly vulnerable urban communities living in informal settlements, many of which in areas exposed to extreme weather.

3.3 Hazard profile: geophysical hazards

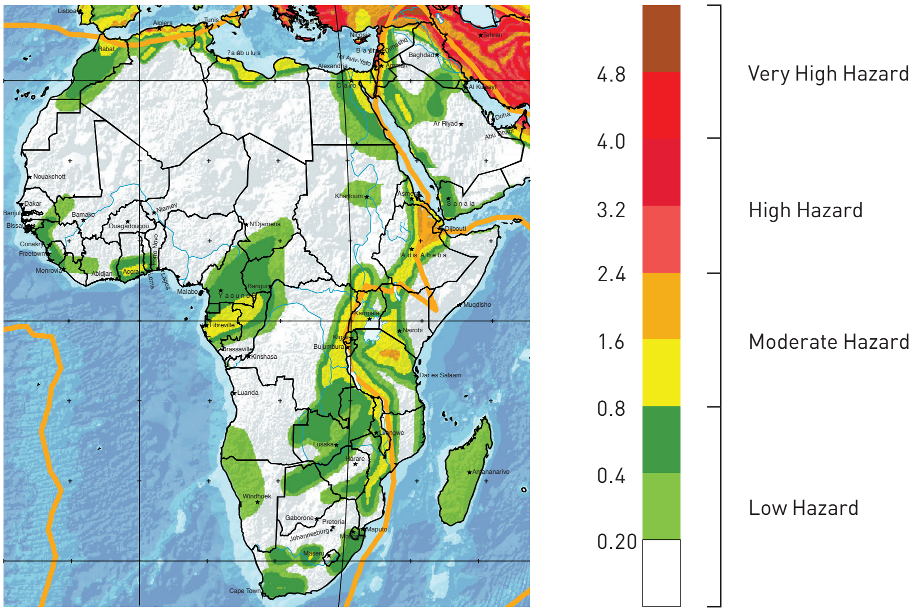
This section examines the status, issues and challenges in relation to the regional seismic and geophysical hazard profile of the Arab states and cities. It further highlights some important vulnerabilities related to the seismic and geophysical hazards facing the main Arab cities.

3.3.1 Seismic and geophysical risks: regional context

The seismicity of Africa is mainly concentrated in two main subregions: North Africa and South-East Africa (Figure 12). Seventy-two per cent of the area of the Arab States (9,975,508 km^2), home to 67 per cent of the population (260,718,000), lies in North Africa. Outside of the East African Rift System (EARS), Africa does not appear to be vulnerable to potentially dangerous seismic activity, although there are a couple of peaks elsewhere. The Middle Eastern region is also significantly vulnerable to seismic risks . The 1,000-km long western boundary of the Arabian plate is a complex plate boundary, extending from zones of sea-floor spreading in the Red Sea to zones of plate convergence in Turkey, and lies along the line of the Gulf of Aqaba, the Dead Sea rift, the Bekaa Valley and the a-Ghab depression. The Horn of Africa has a significant seismic hazard associated with the EARS.[35] The GCC region, due to its location on the Arabian plate, has low exposure to seismic and geophysical hazards.

PGA ≤ 0.10 g corresponds to low seismic hazard
0.10 g < PGA ≤ 0.30 g corresponds to moderate seismic hazard
PGA > 0.30 g corresponds to high seismic hazard

Figure 12
Seismic hazard in the Maghreb, the Mashreq, the Gulf countries and the Southern Tier



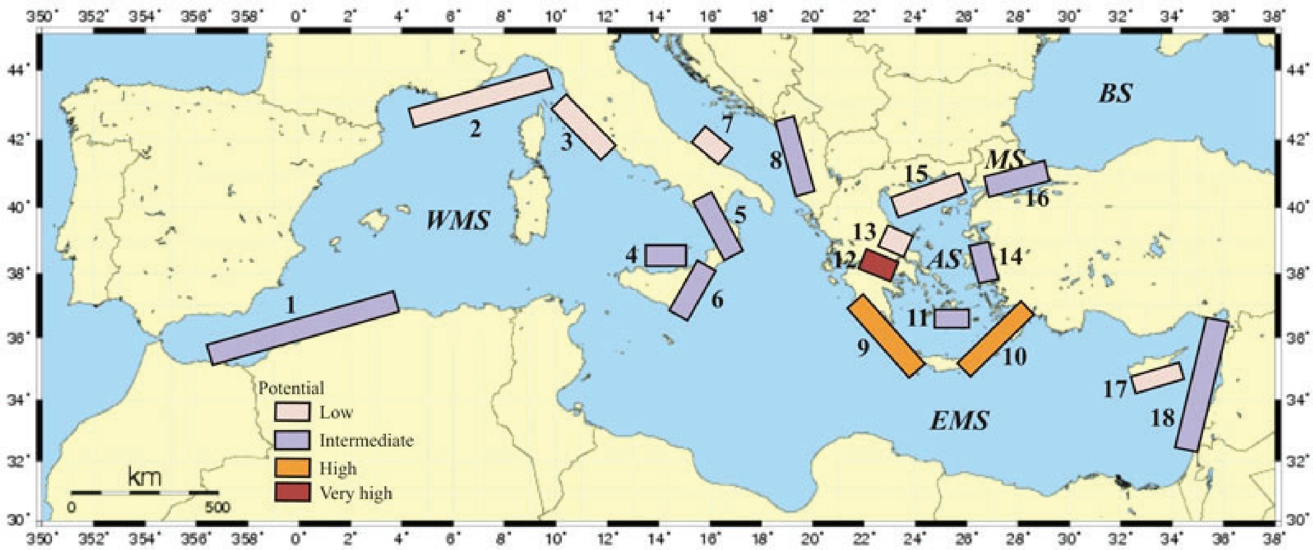
Tsunami records (prehistoric, historical and instrumental) show a long history of tsunami occurrences in the whole Mediterranean Basin from east to west.[36] In the Maghreb, the Moroccan Atlantic coast is highly exposed to tsunamis generated by submarine earthquakes. "The [Atlantic coastal] area of Rabat and Salé is particularly affected by tsunami hazard as reported by historical documents in which inundation related to the tsunami of 1755 reached a maximum distance of 2000 m inland."[37] Since about the second century BC until to the present, there are more or less 22 reliable records of events in the eastern Mediterranean basin. The entire Lebanese coast is also exposed to tsunami hazard. According to Heidarzadeh et al. (2006), the Arabian Gulf cannot be classified as a tsunamigenic zone, but it is exposed to a high-level tsunami hazard due to its proximity to the Makran subduction zone. Figure 13 shows that only western Algeria, eastern Morocco, Syria, Lebanon, Palestine and Egypt may be affected with an intermediate potential tsunami hazard.

FOOTNOTES

[35] PreventionWeb, Horn of Africa: earthquake hazard map. [http://preventionweb.net/go/3870]. Accessed 22 January 2017.

[36] Tinti et al. 2013.

[37] Atillah et al. 2011, p. 3397.



Source: Papadopoulos 2005.

Figure 13
Tsunami prone areas and the tsunami risk in the Mediterranean

3.3.2 Seismic and geophysical hazards in the Maghreb

Earthquake hazard constitutes a constant threat to human life and the environment in the whole of North Africa including Algeria, Egypt, Libya, Morocco and Tunisia. In particular, Algeria, Morocco and Tunisia are the most earthquake-prone areas of the Western Mediterranean basin. Table 9 lists historic events involving magnitudes of more than 6 on the Richter scale. Several devastating earthquakes have occurred in these countries, some even triggering a tsunami, causing heavy loss of life and considerable economic damage in the region.

Table 9
Earthquakes with a magnitude of more than 6 in the Maghreb

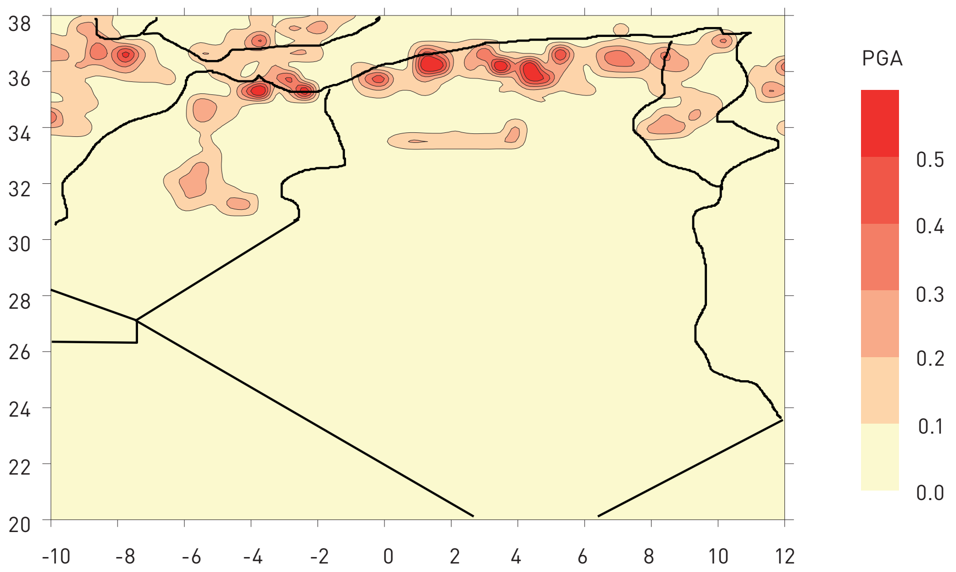
Country	Magnitude above 6 earthquakes in the period (1900-2015)*
Algeria	1910 June 24 Aumale, (M 6.6); 1954 Sep. 9 El-Asnam (actually Cheliff), (M 6.8); 1980 Oct. 10 El-Asnam (actually Cheliff), (M 7.2); 1994 August 18 Mascara, (M 6.0); 2003, May 21 Boumerdès, (M 6.8)
Morocco	2004, Feb. 24 Al Hoceima, (M 6.2)
Tunisia	1915 July 11 Tunis, (M 6.2); 1941 December 27 Tunis, (M 6.8)
Mauritania	NONE
Libya	1935 April 19, Al Qadahia, (M 7.1)

* Magnitudes of earthquakes earlier than 1935, or of those for which there are no instrumental data, are derived from macroseismic observations (using calibration relationships). For more details, see Benouar 1999.

The maximum values obtained for the peak ground acceleration (PGA) in these countries range between 0.15 g and 0.63 g and are located mainly in northern Algeria, eastern Tunisia, around Tripoli in Libya, around the Gulf of Aqaba, and at the entrance of the Gulf of Suez in

Egypt. A detailed analysis[38, 39] of the seismicity of Algeria, Morocco and Tunisia (Figure 14) indicates a value of about 0.4g in Al Hoceima (Morocco), Cheliff, Blida, Setif and Boumerdès (Algeria) and in Tunis (Tunisia).

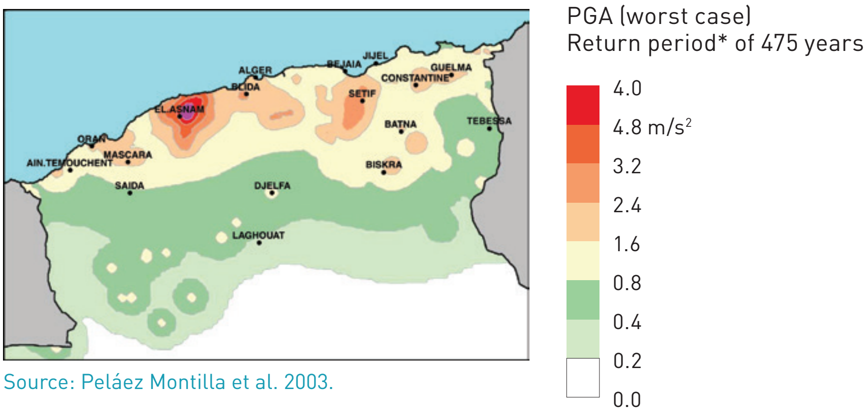
Figure 14
PGA for a 10 per cent probability of exceedance in a 50-year period (475-year return period)



Source: Benouar 1994.

Algeria: Earthquake hazard in Algeria poses an incessant threat to human life and the environment. Rapid urbanization, the development of critical structure, such as dams and oil facilities, the industrialization of cities, and the concentration of population in hazardous areas are all matters of growing concern in Algeria. Figure 15 shows that the PGA values vary from 0.40 g to 0.45 g for a return period of 475 years in El-Asnam (actually Cheliff), with mean values of 0.35 g in Algiers, Boumerdès, Tipaza and Blida and their surroundings, and 0.20 g for the city of Setif. Most of the northern area of Algeria has a mean value of 0.12 g with a mean value of 0.06 g for the southern region, including the cities of Saida, Djelfa, Laghouat and Tebessa. Further south, the Sahara is an earthquake-free region due to its intraplate location.

Figure 15
PGA values for the main cities in Algeria



Source: Peláez Montilla et al. 2003.

FOOTNOTES
[38] Benouar 1994.
[39] Benouar et al. 1996.

Table 10
PGA values for 475-year return period for 12 selected cities in Algeria

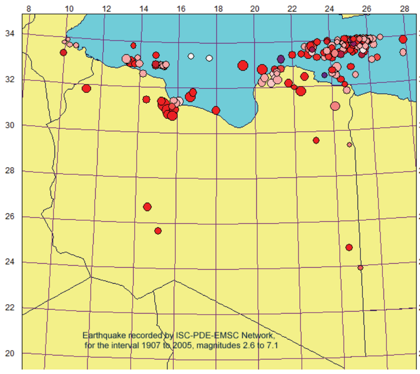
City	PGA (g)	City	PGA (g)
Echeliff	0.45	Guelma	0.19
Algiers	0.35	Oran	0.19
Boumerdès	0.35	Mascara	0.18
Blida	0.35	Batna	0.16
Tipaza	0.35	Bejaia	0.14
Setif	0.25	Aïn Temouchent	0.11
Constantine	0.20	Jijel	0.10

Source: Peláez Montilla et al. 2003.

Algeria is also prone to landslides, with the city of Constantine most affected. The landslides are caused by both natural and anthropogenic factors: the rugged topography of the area, water infiltration mainly due to the obsolescence of the water supply network, unplanned urbanization, the levelling of hill summits by colonial authorities to build residential neighbourhoods for the settlers, and the creation of vast alluvial surfaces to support the construction. The most devastating cases[40] of landslides occurred in 1910 (a slippage of the Sidi Rached bridge) and in 1911 when a huge landslide carried about 200,000 m^3 of earth to the bottom of the north side facing Moulin Carbonnel.

Libya: The whole country is characterized by low to moderate levels of seismic activity, however, a number of earthquakes are reported to have occurred in Libya, including a major earthquake of M = 7.1 on 19 April 1935. Seismic activity in Libya is concentrated in the northern part of the country particularly in the Hun Graben and Al Jabal Al Akhdar regions. The number of earthquakes recorded in Libya is not representative of the actual total number because of the limitations on instrumental sensitivity before 1950, as well as the lack of seismological stations in Libya itself. Suleiman et al. (2001) suggest, however, that for the period 1935-2001 most of the activity has been clustered in two areas: the NNW trending Hun Graben and the Al Jabal Al Akhdar to the north-east of Libya.[41] The highest levels of activity are concentrated in Cyrenaica (north-eastern region) and around the Hun Graben (north-central region). The southern part of Libya is considered to be seismically stable.[42]

Figure 16
Distribution of seismicity in Libya



Source: Elmelade 2012.

FOOTNOTES

[40] Benazzouz 1991.

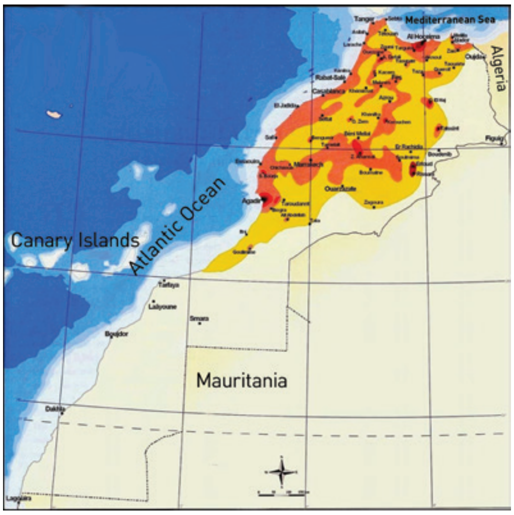
[41] Suleiman et al. 2004, p. 553.

[42] Hassen 1983.

Mauritania: Mauritania is located south of Morocco within the Africa intraplate. According to several bibliographical sources, Mauritania is not affected by earthquakes.

Morocco: Analysis of the macro-seismic and instrumental data for Moroccan seismic activity over more than a century (1901-2010) shows that seismic activity there is relatively moderate compared to other Mediterranean countries. There have been, however, a few earthquakes with a magnitude greater than 6. A review of historical documents shows that much larger earthquakes have occurred in Morocco in the past, and cities like Fez, Meknes, Melilla and those along the Atlantic coast between Tangier and Agadir have suffered damage several times due to earthquakes.[43] The Agadir earthquake in 1960, for example, destroyed the city along with several villages, causing 12,000 deaths. The Moroccan seismicity map shows that seismic activity is concentrated in the Rif domain, mainly in the Al Hoceima region, in the Middle and High Atlas and in the Western Rif where a significant NW-SE seismic line is observed, starting roughly in the vicinity of Fez and passing between Larache and Asilah, through Ouezzane.

Figure 17
Map of maximum intensity observed in Morocco from 1901 to 2010



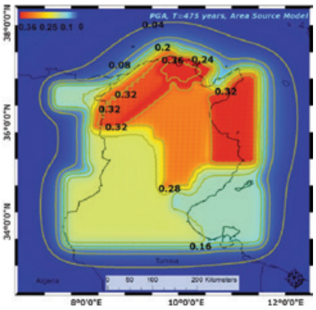
Intensity (MSK-64)
- IX and X
- VIII
- VII
- VI
- V
- <V or unknown

Source: Cherkaoui and El Hassani 2012.

Tunisia: The seismicity of Tunisia is considered moderate when compared to its neighbouring countries (the PGA does not exceed 0.36 g for an area source in 50-year time period). Most instrumental magnitudes fall in the range between 2.0 and 5.5, according to the local seismic bulletin. However, with a level of acceleration of 0.3 g, the location of Tunis places it at an intolerable level of seismic risk, especially when combined with the local building regime in the old city of Tunis as well as the older nineteenth century buildings in the modern city. In addition, given the specific lithological context of Tunis, it is expected to reach a considerable level of amplified acceleration and consequently suffer greater seismic losses. A seismic hazard assessment for Tunisia was conducted using different PGA maps based on three different seismic source models.[44] The findings are shown in Figures 18a, 18b and 18c according to three source models, and Figure 18d shows the combined PGA for a return period of T = 475 years.

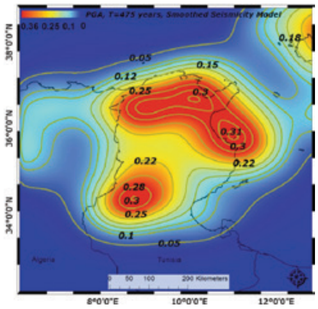
FOOTNOTES
[43] Cherkaoui and El Hassani 2012.
[44] Ksentini and Bouden Romdhane 2014.

Figure 18
Major seismotectonic structures of Tunisia and PGA maps according to different seismic source models.

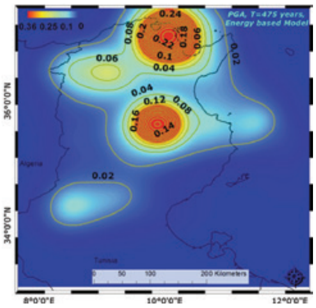


Structural map of Tunisia, showing major seismotectonic faults

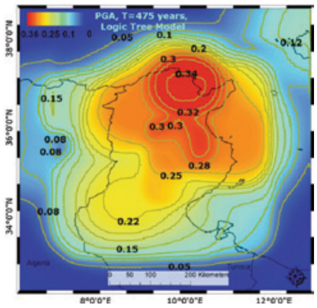
A (Cornell 1968) classical zonal method.



B (Woo 1996a) smoothed-gridded seismicity model.



C (Lapajne et al. 2003) energy based model.



D The logic tree PGA map.

PGA (in g) for a 475-year return period

g: A unit of gravitational force equal to that exerted by the earth's gravitational field. Near the Earth's surface, gravitational acceleration is approximately 9.8 m/s2.

Source: Ksentini and Bouden Romdhane 2014.

3.3.3 Seismic and geophysical hazards in the Mashreq

The Middle East lies at the intersection of three major tectonic plates (i.e., the African, Arabian and Eurasian plates), resulting in very high tectonic activity. Seismic activity in the Eastern Mediterranean region (EMR) is mainly associated with the northward movement of the Arabian plate.[45] Total displacement is estimated at about 107 km since the Oligocene era, with an annual rate of about 0.5 cm over the past 7-10 million years. Due to this tectonic setting, seismicity and topography, the EMR has been subjected to earthquake disasters throughout the past two thousand years. Some of the most significant earthquakes in the Middle East affected most countries in the region.[46]

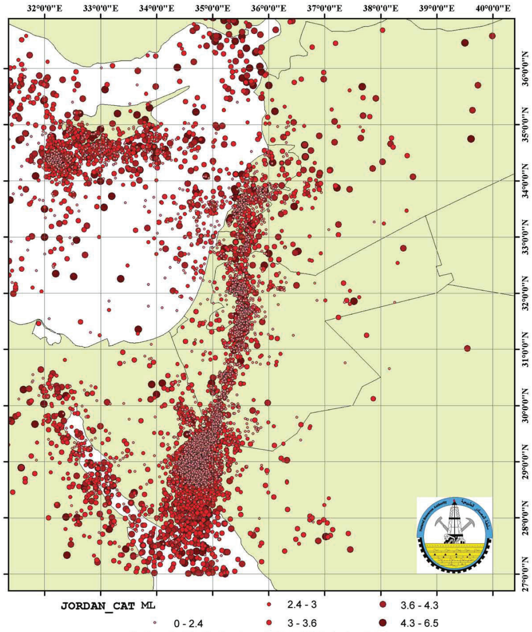
Figure 19 shows the seismogenic zone and epicentres of Gulf of Suez, Gulf of Aqaba, Jordan, Syria and Lebanon.

FOOTNOTES

[45] Jreisat and Yazjeen 2013.

[46] M. Erdik et al., "Assessment of seismic hazard in the Middle East and Caucasus: EMME (Earthquake Model of Middle East) Project", Proceedings of fifteenth World Conference on Earthquake Engineering (Lisbon, Portugal, 2012), Paper No: 2100.

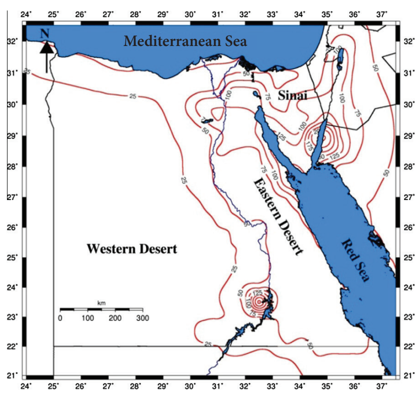
Figure 19
Earthquake distribution in Jordan and the Middle East from 1900 to 2005.



Jreisat and Yazjeen 2013.

Egypt: There are four major seismic zones in Egypt, known as the Northern Red Sea-Gulf of Suez-Cairo-Alexandria trending NW-SE; the Gulf of Aqaba-Levant Fault, NNE-SSW; the Eastern Mediterranean-Cairo-Faiyum, NE-SW; and the Egyptian Mediterranean Coast, E-W.[47] The PGA across Egypt ranges from 0.02 g in middle area of the Western Desert to 0.22 g in the most north-eastern part of Egypt near to the geological origin of the Gulf of Aqaba, with earthquakes of a magnitude 7.2 for a 475-year return period. The most recent seismic hazard assessment for Egypt identified the Aqaba region (Jordan–Egypt border) as the area with relatively highest seismic hazard in the country, which is characterized by moderate seismic activity. The second active area is the entrance to the Gulf of Suez. In the southern part of Egypt, high seismic activity is observed around the Aswan area. There are also some areas with relatively higher seismic activity than their surroundings, such as the Dahshour area, the Cairo area Suez District, the Beni Seuf area and the Abou-Dabbab area.[48]

Figure 20
Mean PGA (cm/s2) on rock sites with 10 per cent probability of exceedance in 50 years (475-year return period) for Egypt



Source: Abou Elela et al. 2012.

FOOTNOTES

[47] Amos Salmon et al., "Seismotectonics of Sinai subplate-eastern Mediterranean region", Geophysical Journal International, vol 155, No. 1 (September 2003), pp. 149-173, doi:10.1046/j.1365-246X.2003.02017.x.

[48] Abou Elela 2012.

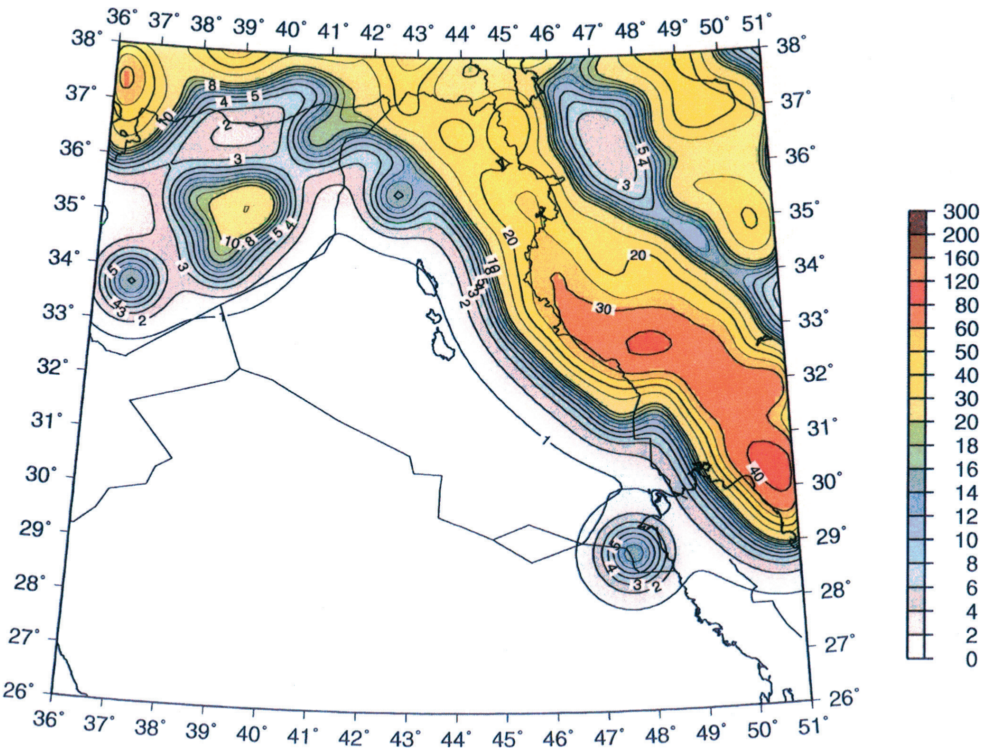
Iraq: Tectonically, Iraq is located in a relatively active seismic zone on the north-eastern boundary of the Arabian plate. Iraq has a well-documented history of seismic activity, with annual activity of varying strengths. An earthquake catalogue has been published for Iraq for the period 1900-1988, which contains 1,031 historical events with magnitudes ranging between 3.7 and 7.4 on the Richter scale.[49]

Seismic hazard investigations have also been carried out and a seismic zoning map compiled, in addition to a seismicity index map, a seismic source map, an iso-acceleration map and a seismic regionalization map. Relatively large and destructive earthquakes cannot be ruled out in this region.

City	PGA (g)
Baghdad	0,02 g
Mosul	0.09 g
Kirkuk	0.09 g
Basra	0.01 g

According to Schwark (2005), north-eastern areas of Iraq lie within a region of high seismic hazard. Since the country does not appear to enforce a system of seismic building codes, major cities, such as Kirkuk, Mosul, Erbil and even the capital Baghdad, are at significant risk of severe damage and loss of life in the event of even a moderate magnitude earthquake. Similar to Mosul, Kirkuk is located in the seismically northern portion of the country and therefore lies within the region of high seismic hazard that may experience 10 per cent probability of exceedance for 50 years a PGA of 0.15 g.

Figure 21
Seismic hazard map for Iraq showing PGA for the 10 per cent probability of exceedance in 50 years



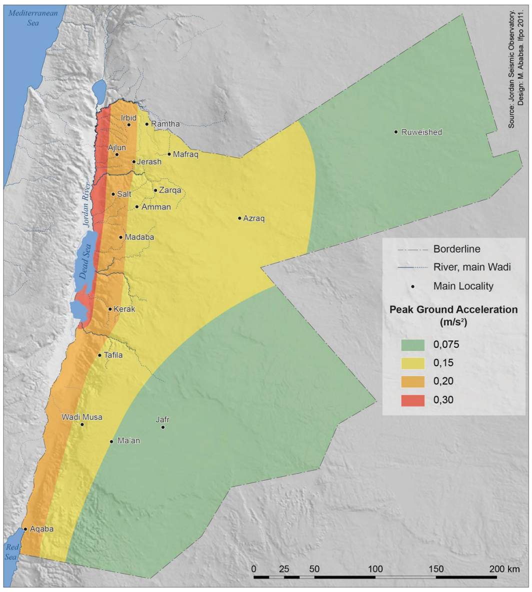
Source: Schwark 2005, p. 55.

FOOTNOTES
[49] The use of the Richter scale for events occurring before its invention is roughly explained in Table 9, note *

Jordan: "Jordan covers the north-western part of the Arabian plate which is separated from the African Plate along the most profound tectonic event on the earth's crust: the Aqaba-Dead Sea-Jordan Valley rift. This is an active pull-apart with left-lateral motion. The amount of left-lateral motion along the Transform in the Dead Sea region has been estimated at 105 km"[50] (with an annual rate of about 0.5 cm over the last 7-10 million years). The Jordan valley, a major part of the Dead Sea Transform (DST), is the most seismically active region in the Middle East, with a history of four thousand years of documented destructive earthquakes.[51] The occurrence of strong earthquakes along the DST fault system is a major threat to the public safety and economy of the Middle East.

The Jordanian National Building Code divides the country into four seismic zones: 1, 2A, 2B and 3 with increasing hazard towards the Dead Sea Transform.

Figure 22
Peak ground acceleration for a 10 per cent probability of exceedance for a 50-year timespan, corresponding to 475-year return



Source: Jreisat and Yazjeen 2013.

Landslides in Jordan have caused numerous problems over the past 40 years. The most critical slides occurred during the period 1991-1992 following exceptionally heavy rain and snowfall.[52]

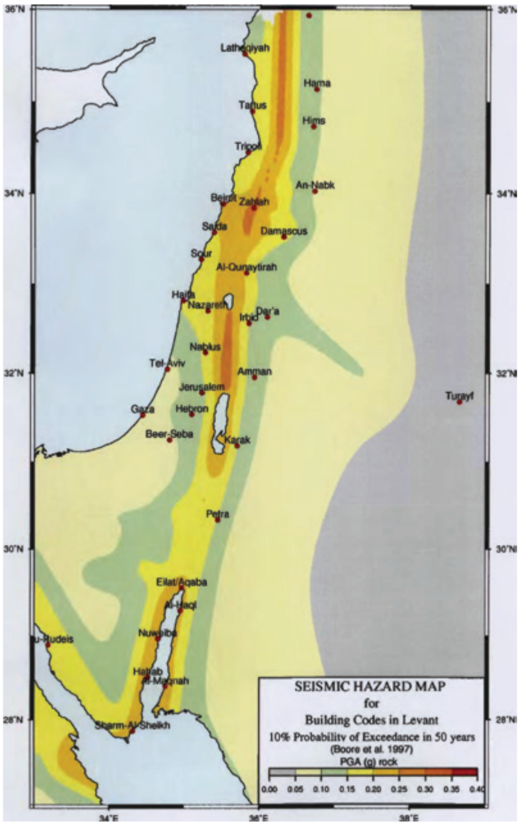
Palestine: Palestine shares the same tectonics along its border with Jordan. All seismic hazard studies include both countries. Figure 24 shows the seismic hazard for a 10 per cent probability of exceedance of the PGA in a 50-year timespan (i.e., a 475- year return period) based on Boore et al. (1997) in the Levant, including all of Palestine (Quennell 1958; Freund et al. 1970). It should be noted that the PGA in Gaza is estimated at between 0.05 g and 0.10 g, in Al-Quds between 0.10 g and 0.15 g, in Nablus between 0.15 g and 0.20 g, and about 0.30 g in Ariha.[53]

FOOTNOTES

[50] Jreisat and Yazjeen 2013, citing Quennell 1958; Freund et al., 1970.
[51] Shapira et al. 2007.
[52] Abdallah et al., 1996.
[53] Shapira et al. 2007.

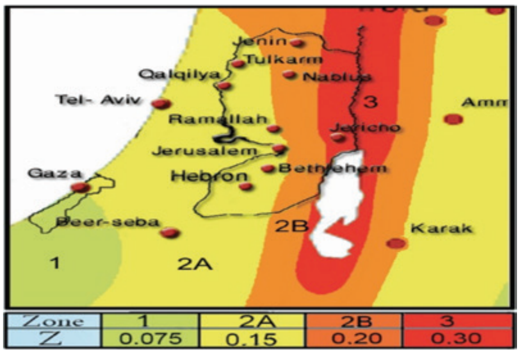
Figure 23
Seismic hazard for a 10 per cent probability of exceedance of the PGA in a 50-year timespan (475-year return period)

Source: Shapira et al. 2007, p. 73.



Source: Shapira et al. 2007, p. 73.

Figure 24
Seismic zoning map of central Palestine and Jordan



Lebanon: "The country lies along the 1,000-km long left-lateral Levant fault system (LFS)... This fault system is responsible for a significant number of seismic events in the eastern Mediterranean."[54] The PGA for a 50 year timespan (a 475-year return period) in the Lebanese territories varies between 0.2 g in the eastern part of the country to 0.30 g in the western part near the coastal area between Saida and Tripoli, where most of Lebanon's population and capital investments are located. This implies that all civil engineering facilities, including buildings and bridges, that have still to be constructed in the coastal zone between Saida and Tripoli should be designed to a "high seismic hazard" standard according to the design and reinforcement requirements as laid down in international codes of practice.[55] Further

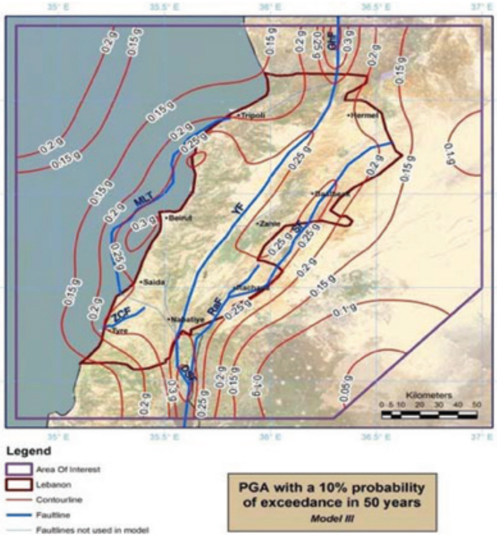
FOOTNOTES

[54] Huijer, Harajli and Sadek 2011, p. 68.

[55] Ibid.

to the combined effects of natural and human-caused factors, floods and landslides cost Lebanon around 10-15 million dollars per year, along with numerous fatalities and injuries.[56]

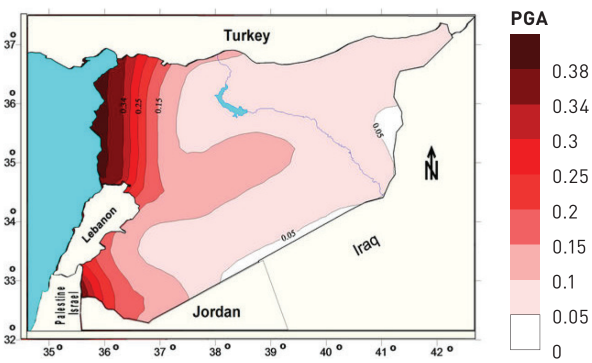
Figure 25
Seismic hazard map of Lebanon, distribution of PGA for 50-year period (return period of 475-years).



Source: Huijer, Harajli and Sadek 2011. p. 78.

Syria: Syria lies on the northern part of the Arabian plate. The seismicity of Syria may be qualified as moderate if the period of study is restricted to the last two centuries. "The Syrian territory can be divided into three main tectonic regimes: The first one is the Dead Sea rift system, which is represented by an N-S left-lateral strike-slip faults system. The second one is the Palmyrides mega-tectonic shear zone, which is characterized by highly repeated folding and the NE-SW faults system. The third tectonic zone is the Euphrate system, which is characterized by the NW-SE normal faults system."[57] Figure 26 demonstrates that "the maximum expected design value of PGA (0.46 g to 0.5g for R.P.[58] 475 years) is concentrated at the north-western part of Syria (i.e., the cities of Iskenderun, Latakia and Tartous). According to the Syrian Building Code (1995), the design PGA value (0.4 g for R.P. 1000 years) applies to all western parts of Syria (Idlib, Aleppo, Iskenderun, Latakia, Tartous, Dara, as well as some parts of Hama, Homs, Damascus and Swaida cities). Also some parts in the centre of Syria (Palmyra)."[59]

Figure 26
Seismic hazard map of Syria, distribution of PGA for a return period of 475 years



Source: El Ssayed et al. 2012, p. 853.

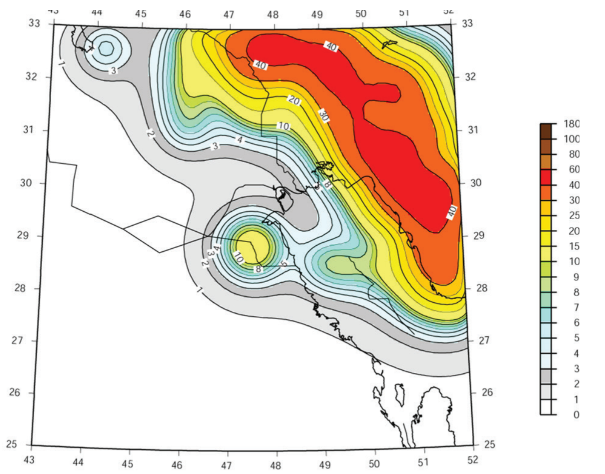
FOOTNOTES
[56] UNESCO 2010, p. 15, citing Khawlie 2000.
[57] El Ssayed et al. 2012, p. 847, citing Cornell University 2001.
[58] return period.
[59] Ibid, p. 854.

3.3.4 Seismic and geophysical hazards in the Gulf Arab States

All Gulf countries are found on the Arabian plate, which is considered to be a stable continental region.[60] Until quite recently, the seismic hazard in the Arabian Gulf states was considered to be negligible. Dubai, Abu Dhabi, Bahrain and Doha were classified as zone 0 (i.e., no seismic design requirements).[61] However, "the publication of the Global Seismic Hazard Assessment Program (GSHAP) map (Shedlock et al. 2000) as well as the recent occurrence of locally felt earthquakes, such as the March 11, 2002 Masafi event, have led to a perceived need for revision of this assessment."[62]

Kuwait: The State of "Kuwait is located to the south-west of the Zagros belt which is capable of producing strong earthquakes with magnitudes of up to 7.5. Local seismicity in Kuwait has been characterized by several local earthquakes of magnitudes up to 5, mainly in the southern part of the Minagish oil fields."[63] Earthquakes with local magnitudes near and above 4 have occurred in Kuwait in the last decade.[64] The mean PGA for a return period of 475 years varies from 0.002 g to 0.020 g.[65]

Figure 27
Seismic hazard map of Kuwait, distribution of PGA with 10 per cent Probability of Exceedance for 50-year timespan (return period of 475 years).

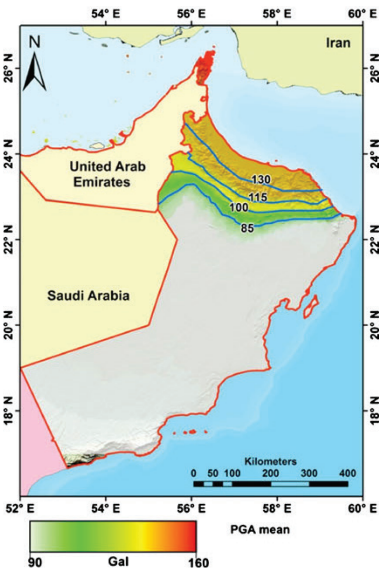


Source: Al-Enezi 2006.

FOOTNOTES
[60] EPRI 1994.
[61] Al-Haddad et al. 1994.
[62] Pascucci et al. 2008.
[63] Sadek 2001.
[64] Al-Awadhi and Midzi 2001.
[65] Al-Enezi 2006.

Oman: The Sultanate of Oman forms the south-eastern area of the Arabian plate, which is surrounded by relatively high active tectonic zones. Deterministic seismic hazard assessment maps suggest the relatively higher seismic hazard activity in the north-eastern part of the country. The mean PGA across Oman ranges from 0.08 g in the south and central areas, up to about 0.16 g in the extreme north (Figure 28). "The seismo-tectonic settings around Oman strongly suggest that large earthquakes are possible, particularly along the Arabian plate boundaries."[66] Therefore, it is important that critical structures, such as airports, harbours, telecommunications, hospitals, schools and other services, are resilient to earthquakes. A large part of the Sultanate of Oman falls into a seismic zone where a MM Intensity VII seismic event could occur.

Figure 28
Deterministic seismic hazard assessment for Oman.



Source: Deif et al. 2012.

United Arab Emirates (UAE): The UAE has a low to moderate seismic hazard potential. Large parts of the UAE lie within zone 0 with less than 50 cm/s2 (0.05 g). Greater Abu Dhabi area lies in zone 1, where the PGA is between 0.05 g and 0.10 g. Zone 2A, where the PGA is between 0.1 g and 0.20 g, covers the Greater Dubai, Sharjah and Ajman area. The highest PGA in the Fujairah area approaches 0.20g (Figure 29). No part of UAE lies within zone 2B or zone 3.[67] "There are currently no well-established seismic code requirements for structures in the Arabian Peninsula states. However, both the Abu Dhabi and Dubai municipalities recommend that for buildings of five or more stories the Zone 2A design criteria in UBC 1997 should be applied. Further recommendations on seismic hazard levels in the Arabian Peninsula can be found in the Guide to Design of Concrete Structures in the Arabian Peninsula prepared by the Concrete Society (2007), which indicates a moderately low seismic hazard for most of the cities in the Arabian Gulf region."[68]

FOOTNOTES

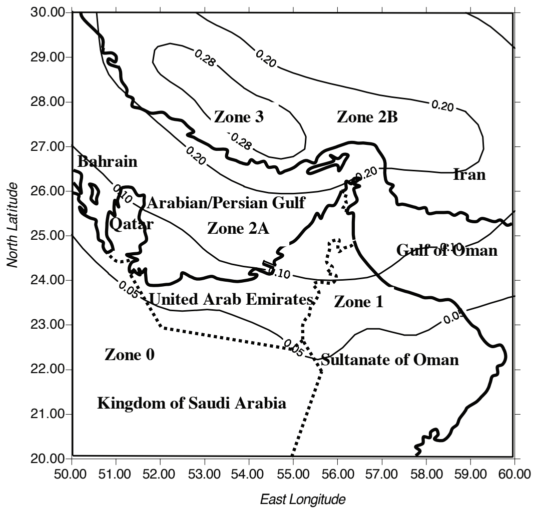
[66] Deif et al. 2012.

[67] Abdalla and Al-Homoud 2004.

[68] Pascucci et al. 2008.

Figure 29

Seismic zoning map for UAE, Bahrain, and Qatar showing five zones (0, 1, 2A, 2B and 3) for 475-year return period.



Source: Abdalla and Al-Homoud 2004.

Bahrain and Qatar: Bahrain and Qatar are located in seismic zone 1 and the probabilistic seismic hazard assessment for these two Gulf countries, with a 10 per cent exceedance probability for a timespan of 50 years (475-year return period), varies between 0.04 g and 0.12 g.

Saudi Arabia: Saudi Arabia forms the largest part of the Arabian plate. Harrat Al-Shaqah is one of the provinces in western Saudi Arabia, (also known as Harrat Lunayyir) to experience recent volcanic activity in which there was an "intense earthquake swarm due to magmatic intrusion. Numerous small to moderate size earthquakes occurred in May-July 2009 [...] recorded by the Saudi National Seismic Network (SNSN) operated by Saudi Geological Survey (SGS). More than 27,000 earthquakes occurred, 207 of which were felt in and around Harrat Al-Ahaqah [*sic*], up to distances of more than 210 km. The most intense activity was 17-19 May when a ML 5.39 earthquake occurred."[69] The seismic hazard potential[70] in Saudi Arabia is fairly low with an expected bedrock horizontal PGA in the range of 0.04 g to 0.06 g for a return period of 475 years.[71]

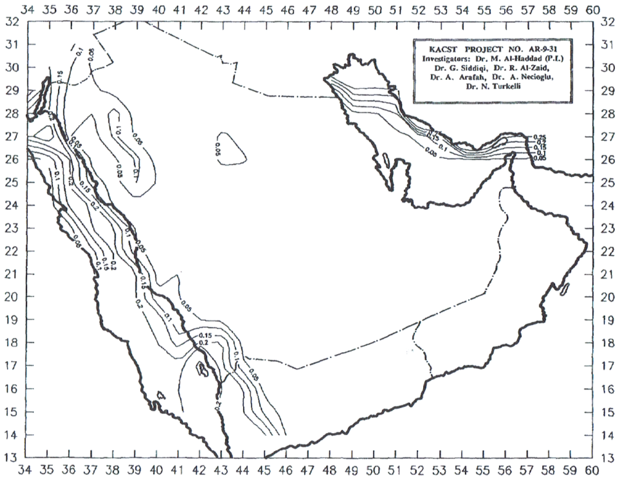
FOOTNOTES

[69] EPRI 1994.

[70] H. Zahran and Yousef Salah El-Hadidy, "The 2009 volcanic and seismic activity in Harrat Al- Shaqah (Lunayyir), western Saudi Arabia," *Reduction of Earthquake Losses in the Extended Mediterranean Region* (RELEMR) Workshop Report Lisbon, Portugal, 26-29 October 2009 (Paris: UNESCO 2010).

[71] Pascucci et al. 2008.

Figure 30
PGA (cm/s2) with a 10 per cent probability of exceedance in a 50-year timespan (475-year return period)



Source: Abdalla and Al-Homoud 2004.

3.3.5 Seismic and geophysical hazards in the southern tier countries

The northern Nubia-Somalia rift zone between Eritrea, Djibouti, Somalia and Ethiopia is a source of earthquake and volcanic hazards in this region. The great EARS constitutes the complex boundary between the Nubian and Somalia plates and is also the geological home to other significant solid-earth geohazards, namely volcanoes and landslides, including large-scale submarine landslides or continental slope slumping.[72]

Djibouti: Djibouti is located in a geographic area where the process of stretching and dislocation of the crust causes earthquakes and volcanic eruptions. The magnitudes observed by the Geophysical Observatory of Arta are generally between 2.0 and 4.0. Findings show that Djibouti may experience PGA varying from 0.16 g to 0.24 g, which may impact seriously on all types of constructions. In Djibouti, the earth crust is very thin and, because of its high temperature, relatively ductile and therefore less brittle. All this explains the low magnitude of the earthquakes registered in Djibouti. However the situation with particular faults (faults transforming) that cut crosswise over the rift (e.g., between Arta and Tadjourah) may involve higher energies that could trigger earthquakes (fortunately much rarer) of magnitudes 5 or even 6. The 1973 earthquake was the most violent in the last 40 years, although its intensity did not exceed 7.0 on the Mercalli scale. In recent years, urbanization has accelerated, especially in the capital. The expansion of the city to the north, backfilled on land reclaimed from the sea, and south towards Ambouli Wadi, may constitute a real risk in the event of an earthquake. The situation could be further exacerbated due to the exposure to tsunamis.[73]

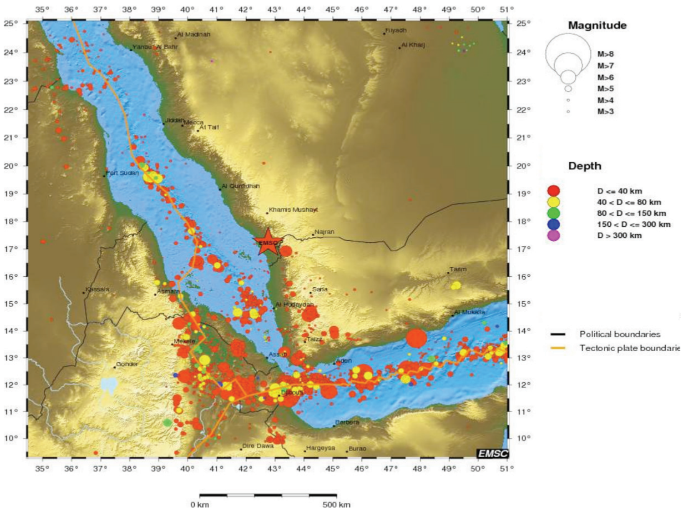
FOOTNOTES

[72] Chris Hartnady, "Tsunami potential on East African coast, western Indian Ocean island states," *Disaster Reduction in Africa - ISDR Informs*, No. 5 (Nairobi: UNISDR 2005), pp. 22-24.

[73] Stratégie nationale de gestion des risques et des catastrophes de Djibouti (2014).

Figure 31

Earthquake epicentre map for Djibouti and its surroundings in the period 1960 to 2014 (EMSC)



Source: Earthquake epicenter map of Djibouti and its vicinity from 1960 to 23 January 2014 European-Mediterranean Seismological Centre (EMSC) Manual location.

Somalia: According to GSHAP,[74] in Somalia the seismic hazard is very low, varying from less than 0.01 g to 0.03 g, which is too small to cause any damage to the built structures, even those which are highly vulnerable.

Sudan: Sudan lies within an intraplate region (Nubian Plate) in the centre of Africa. This region is bounded by active tectonic features, such as the Red Sea Rift to the north-east and the EARS to the south and south-east. The seismicity map of Sudan shows that large parts of Sudan, specifically western and north-western Sudan, lie in zone 0. South-western Sudan lies in zone 1, where the PGA is between 0.05 g and 0.10 g, and covers most of central Sudan and north-western Sudan. Although there has been an increase in the magnitude and frequency of seismic events in many parts of the Sudan, most buildings and structures have not yet been designed and constructed in accordance with earthquake provisions, nor has any consideration been given to earthquake effects.[75] The seismic vulnerability of buildings is high in moderate and high seismic zones.

FOOTNOTES

[74] GSHAP 1999.

[75] Abdel Wahab, Mohamedzein and Abdalla 1999, pp. 36-46.