LLOYD'S

Emerging Risks Report 2017

Natural Environment

Seismic Shock
A new earthquake model for the Middle East

CatRisk Solutions
Catastrophe Risk Management Technology

oasis LOSS MODELLING FRAMEWORK

Lloyd's of London Disclaimer

About Lloyd's

Lloyd's is the world's specialist insurance and reinsurance market. Under our globally trusted name, we act as the market's custodian. Backed by diverse global capital and excellent financial ratings, Lloyd's works with a global network to grow the insured world – building the resilience of local communities and strengthening global economic growth.

With expertise earned over centuries, Lloyd's is the foundation of the insurance industry and the future of it. Led by expert underwriters and brokers who cover more than 200 territories, the Lloyd's market develops the essential, complex and critical insurance needed to underwrite human progress.

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Trevor Maynard PhD, MSc, FIA has degrees in pure maths and statistics and is a Fellow of the Institute of Actuaries. He is Head of Innovation at Lloyd's including responsibility for horizon scanning and emerging risks. Subjects covered in recent years include: the economic and social implications of a food system shock; the effects of cyber-attacks on the US energy grid and an exploration of aggregation modelling methods for liability risks.

He is co-chairman of OASIS, an open modelling platform for catastrophe models and sits on the Board of the Lighthill Risk Network.

Dr Mohammad R Zolfaghari is an earthquake scientist and the director of CATRisk Solutions Ltd, a UK-based catastrophe loss modelling firm. He holds an MSc in geotechnical engineering and a PhD in earthquake engineering and engineering seismology from Imperial College of London. Since starting his company in 2005, he has been involved in developing catastrophe loss models for more than 35 countries in Europe, Asia, Africa, Middle East and Latin America.

Dr Zolfaghari has more than 26 years' experience in natural catastrophe studies and in particular earthquake hazard and risk modelling. He has thorough knowledge of major catastrophe models in the market and his areas of expertise also include: structural earthquake engineering, engineering seismology, probabilistic and statistical methods in natural catastrophe. He has developed several damage estimation and decision making tools for crises management and early-response applications. He has participated in many World Bank and internationally sponsored catastrophe risk management programs and is an active member of the GEM (Global Earthquake Model) program.

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- Trevor Maynard, Head of Innovation
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Executive summary

A region on the up

The Middle East is a rapidly urbanising region and a growing business hub.

Of the 398 million people spread across the region, 56% live in cities. This figure is expected to rise to 68% by 2025.

The area attracts large-scale investment, with six of the largest projects in the United Arab Emirates and Saudi Arabia worth more than US$55 billion. Abu Dhabi is spending US$37 billion on various infrastructure projects up to 2020, including completion a new airport terminal and nuclear power plants.

While these demographic and economic changes are driving growth in the region, they are also concentrating high-value assets and populations in a relatively small area.

This means businesses and communities are becoming more vulnerable to natural hazards such as droughts, floods, storms and earthquakes.

The need for earthquake models

The Middle East has a history of earthquake activity. Between 1900 and 2014, the region has been affected by 200 moderate to large earthquakes. These have killed almost 250,000 people and affected 10 million others.

Today, almost a fifth of the population (about 30 million people) in the countries covered by the model in this report is at risk from earthquakes.

The Lloyd's City Risk Index estimates that US$85 billion of potential economic output of the region's 22 leading cities could be at risk from earthquakes over the next decade.

These serious consequences of earthquake damage make it important to understand earthquake risk in the region better. To do this, insurers need more earthquake models as there are relatively few that cover the Middle East (Israel, Turkey and Cyprus are the exception). Insurers use risk models to make reliable assessments of the severity and frequency of catastrophe risk. This, in turn, helps them create and price catastrophe insurance products.

A new model for the Middle East

The new model described in this report, developed by CATRisk Solutions in partnership with the Lloyd's market, helps fill this gap in Middle East earthquake modelling.

It covers earthquake risk in the following countries: Bahrain, Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates and Yemen.

The model has a number of innovative features that distinguish it from other earthquake models for the region.

- It is based on a bespoke seismotectonic source model that generates thousands of simulated earthquake events for the Middle East, on a site-by-site basis. This gives a more detailed view of earthquake risk in the region than existing models.
- The model covers the entire Middle East region as it includes data from all earthquakes that have occurred there since 400BC. This is an important and unique feature of this model as earthquake damage can be caused by tremors that lie outside a modelled country.
- It includes damage metrics that can produce estimates for each simulated earthquake event in the 10,000-year catalogue the model is based on, allowing insurers to assess potential losses on a site-by-site basis, and across their entire portfolio. Not all other models on the market take damage distributions into account in this way.
- It applies a unique probabilistic approach to hazard uncertainty that allows insurers to see the aggregation of losses in all the countries covered by the model. Other models are designed to give country-specific views only.
- The model is based on the latest information on past seismicity, regional tectonic deformation, location and activity of active faults and, where available, slip rate measured from recent GPS surveys.

The model includes data from all earthquakes that have occurred in the wider Middle East region, and further countries may be added as the model develops and further scientific hazard assessments are made available.

Next steps

There are several ways in which this model and the new approach to building it could be developed further:

- Better quality exposure data from future scientific studies could be added to give a fuller picture of earthquake risk and where it would impact the region - the model's modular design means it can be updated as new scientific information becomes available.
- A better understanding of where damage could occur and the resultant losses could be gained by adding more infrastructure vulnerability metrics.
- The unique approach used by this model could be applied to model design for other earthquake-related hazards, such as tsunamis and landslides. This would allow insurers to gain a more complete picture of the risks posed by earthquake-related hazards.
- New models for perils such as wind and flood could be created using the approach used to design this model. This could create a detailed assessment of other potential threats in the region.
- It is anticipated that this model could encourage further collection of more detailed and reliable exposure data in the region.

Conclusion

For insurance to play its full potential in mitigating and transferring earthquake risk in the Middle East, insurers need better earthquake models for the region.

The model described in this report uses the latest data and new modelling techniques to provide a much-needed, additional earthquake model for the region that is different from others on the market.

This model helps insurers gain a deeper understanding of earthquake risk in the Middle East. It could help them design earthquake insurance products that are specific to the region and provides them with a greater understanding of the exposure risk across their portfolios.

Oasis: an alternative way to buy risk models

This new Middle East Earthquake model is available on the Oasis platform, which is supported by Lloyd's. The Oasis platform offers insurers a new, lower cost way of accessing risk models on a 'shared-services' basis. This means they can access a greater choice of models in multiple regions, making it much simpler for them to obtain multiple views of a single risk. This reduces insurers' dependency on just one or two models, meaning they can form a deeper understanding of risks and their impacts around the world. They can then use this information to fine-tune and more accurately price insurance products. See www.oasislmf.org for more information.

1. Introduction

Several regional and international seismic-hazard studies have found the wider Arabian Peninsula is only exposed to low to moderate seismic activity compared to many surrounding regions. However, there are many urban areas that are exposed to moderate to high seismic activity that – in conjunction with a vulnerable built environment – could result in seismic damages and resultant economic loss. For example, most of the coastal cities of present day Lebanon have been destroyed by historical earthquakes over the past 2,000 years.

The accumulation of large sum insured value and the increasing concern of damaging earthquakes in some cities in this region has highlighted the need for detailed seismic loss modelling, using the latest seismological and engineering information.

To explore the potential to drive innovative solutions in the cat model space, and inform risk understanding, Lloyd's Corporation has facilitated the development of a model at the request of Lloyd's managing agents that covers earthquake risk in the Middle East.

This study introduces the CATRisk Solutions' Middle East earthquake model, and provides an overview of the latest seismological and engineering information in the region by highlighting the hazard, exposure and vulnerability for 11 countries in the Middle East:

- Bahrain
- Iraq
- Jordan
- Kuwait
- Lebanon
- Oman
- Qatar
- Saudi Arabia
- Syria
- United Arab Emirates
- Yemen

The study goes on to illustrate how this knowledge can be used to build a view of risk when integrated into hazard modelling. The approach implemented by CATRisk Solutions uses the latest scientific understanding of:

- Past seismicity
- Regional tectonic deformation
- Location and activity of active faults; and
- Where available, slip rate measured from recent GPS surveys.

This new, innovative approach allows for a full representation of future earthquakes in time and space, along with fault characteristics.

The report is also accompanied by "Seismic Shock: A hazard overview for the Middle East", which describes the state of scientific earthquake knowledge in the regional seismic zones in the Middle East. This will be of interest to anyone looking to gain a greater understanding of the seismic drivers in particular areas of interest.

1.1 Why the Middle East?

Historically, the Middle East has been the site of some of the world's earliest civilisations. Today, the Middle East sees a combined population of 398mn spread across the region *(The World Bank, 2014)*, with some 56% estimated to live in cities. That figure is expected to reach 68% by 2025 *(UN-Habitat, 2012)*.

The geographical distribution of these cities and the density of population in them vary from country to country. Fertile regions and places close to water resources, such as Egypt, are very densely settled with close to 90mn inhabitants *(The World Bank, 2017a)*. Other regions of the Middle East are only lightly populated, such as Oman with only 4.2mn *(The World Bank, 2017b)*.

Other trends driving growth include:

- **Societal development:** The population of the Middle East has increased rapidly during the past few decades, with growth fuelled by revenue from oil and gas resources *(UN-Habitat, 2012)* facilitating development that has led to a sharp decline in death rates.

  In particular, infant and maternal care has improved and the physician/population ratio has risen briskly, leading to better survival rates *(Clawson, 2009)*.

- **Urban development:** Inward migration, driven by demand for labour, regional conflict driving people out of other countries, and the low and volatile income from agriculture *(Johansson De Silva and Silva-Jáuregui, 2004)* has seen rapid growth concentration in urban areas, coastal strips, mountain valleys and along rivers.

  These areas are now home to an estimated 92% of the region's population *(Banerjee et al., 2014)*. Moreover, as opportunity increases in these areas, they act as magnets for employment, trade, health and mobility *(UNISDR-ROAS, 2013)*.

- **Large-scale investment:** The region is home to a number of mega-projects, such as the World Cup to be held in Qatar in 2020, and the Expo 2020 in Dubai.

  As well as a series of international events, there is large-scale investment in infrastructure, with six of the largest project in United Arab Emirates and Saudi Arabia worth more than US $55bn.

  Also in the Gulf region, Abu Dhabi is spending US $37bn on various projects up to 2020, including completion of the Abu Dhabi Louvre museum, a new airport terminal and the nuclear power plants in Barakah *(AMEInfo, 2017)*.

Rapid urbanisation in conjunction with the high concentration of economic assets which comes with it has exposed increasing portions of population and economic value to natural hazards.

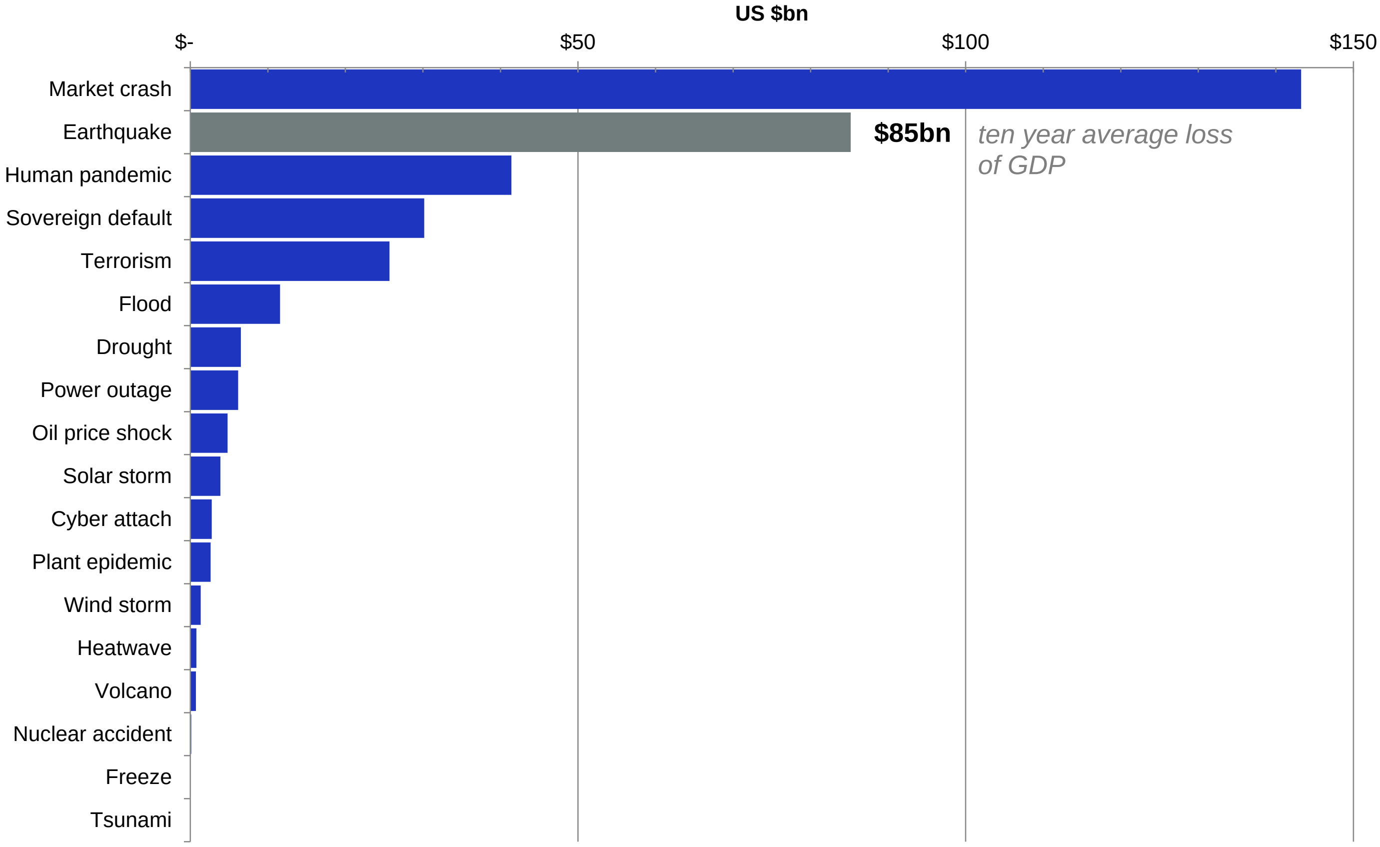
Floods, earthquakes, storms and droughts are among the most frequent natural hazards in this region *(Banerjee et al., 2014)*. This can be seen in the Lloyd's City Risk Index analysis with US $370bn total GDP@Risk[a] in the 22 cities representing 15% of potential economic output over the next decade[b] *(Lloyd's, 2015)*.

[a] The expected loss to a selected location's economic output from all 18 threats. Its calculation combines the likelihood of events occurring during the period 2015-2025 with the ten year average loss of GDP – GDP@Risk – that would result.

[b] The expected loss to a selected location's economic output from all 18 threats as a percentage of its Average annual GDP.

The study shows that US $85bn of the US $370bn of the potential economic output of 22 leading cities in the region could be at risk from natural earthquake hazards, equivalent to 23% of potential economic output over the next decade (*see Figure 1, p8*).

Figure 1: GDP@Risk in the Middle East



The earthquake risk figures in this graph result from the Cambridge Centre for Risk Studies model, which forms the basis of the Lloyd's City Risk Index. These firgures are not derived from the CATRisk Middle East earthquake model.

Solar storm: While the threat itself is not emerging, our vulnerability to the risks it poses is.

Source: Lloyd's

1.2 Risk transfer in the region

The increasing prospect of natural catastrophe losses in in the Middle East means many countries in the region are facing greater challenges in financing disaster recovery and reconstruction from current government budgets *(Banerjee et al., 2014)*. Financial authorities in such countries are looking for approaches to transfer risk responsibility to households and businesses in exposed areas through insurance mechanisms *(OECD, 2012)*.

According to research by the Global Facility for Disaster Reduction and Recovery (GFDRR), United Nations Development Program (UNDP), United Nations Office for Disaster Risk Reduction (UNISDR), and the World Bank, governments across the region are increasingly seeking comprehensive disaster risk management services *(Banerjee et al., 2014)*, which opens the opportunity for structures and policies that insurance can play a vital role in underwriting human progress.

Risk transfer through insurance industry has been effective in many developed countries with well-established private-sector insurance structures that are capable of spreading risk nationally and internationally. However, there are other factors controlling these rates, such as the presence of insurance regulatory bodies and other commercial considerations in unregulated competitive markets *(CISL, 2015)*.

Many countries in this region are taking their lead from international trends and considering risk financing measures through market-based catastrophe risk insurance. However, the level of understanding of catastrophe risks in the Middle East is relatively low and consequently there is a need for model-based risk assessments in order to facilitate sustainable risk-transfer solutions.

1.3 Catastrophe modelling

Essential to any efforts towards any sustainable natural catastrophe risk management and in particular risk transfer mechanism in the form of insurance, is a reliable assessment of the severity and frequency of potential future catastrophe risk. Catastrophe risk models are a key element for such assessments in today's insurance and reinsurance market. The accumulation of large sum insured value and the increasing concern of damaging earthquakes in some cities in this region highlights the need for detailed seismic loss modelling, using the latest seismological and engineering information.

With the exception of Israel, Turkey and Cyprus, there is currently very little catastrophe model coverage for earthquakes in the Middle East (*see Table 1, below*):

Table 1: Earthquake catastrophe model coverage for the Middle East

Country	AIR Worldwide	CoreLogic	Risk Management Solutions	CATRisk Middle East Quake Model (CATRISK-MEQM)
Bahrain	–	✓	–	✓
Cyprus	✓	✓	–	–
Egypt	–	–	–	–
Iran	–	–	–	*
Iraq	–	–	–	✓
Israel	✓	✓	✓	–
Jordan	–	–	–	✓
Kuwait	–	–	–	✓
Lebanon	–	✓	–	✓
Oman	–	✓	–	✓
Palestine	–	–	–	–
Qatar	–	✓	–	✓
Saudi Arabia	–	✓	–	✓
Syria	–	–	–	✓
Turkey	✓	✓	✓	–
United Arab Emirates	–	✓	–	✓
Yemen	–	✓	–	✓

** This model is not included in CATRisk MEEQ model available to Lloyd's managing agents, but is available as a separate add-on on request.*

Source: Lloyd's[c]

This gap led to the commissioning of a new model by Lloyd's, which has been developed by CATRisk Solutions. for use on the Oasis Loss Modelling Framework (Oasis LMF) platform.

[c] Correct as of 2 February 2017.

1.4 Facilitating innovation

Over the past few years catastrophe loss models have grown in sophistication and have now become a critical part of pricing risk and managing solvency across the market. The existing model vendors have served the market well, based on currently available technology and data, and will continue to do so. However, for some time Lloyd's has also supported the concept of an open framework for modelling, and has done this by supporting the Oasis Loss Modelling Framework (Oasis LMF).

1.4.1 Oasis Loss Modelling Framework

Oasis Loss Modelling Framework (Oasis LMF) is a not-for-profit company limited by guarantee and owned by its members, who comprise organisations including Lloyd's, and (re)insurers and brokers in the UK, Bermuda, Zurich and the US.

The Oasis LMF is a plug-and-play solution that, through standardisation, is intended to allow multiple model developers to prepare models in the knowledge they are in a format the insurance industry has endorsed and can use immediately. By doing this, Oasis LMF aims to create and foster links through the wide community of those interested in modelling catastrophe risk across business, academia and government *(Oasis Loss Modelling Framework, 2017a)*.

The framework

The Oasis framework defines the way in which hazard, damage, exposure, and insurance policy data can be combined to calculate exposure to catastrophe. Its portfolio of plug-and-play models aims to simplify the process for new entrants to come into the catastrophe model market. By providing access to the simulation kernel and financial module for free – the part of the model that computes financial losses by applying insurance terms and conditions – Oasis LMF allows new players to share their models and views of risk with the market.

A number of enterprises from around the world have already joined as associate members, including the UK Met Office, University College London, Karen Clark & Co., JBA Risk Management and Perils AG

The European Union-funded Climate-Knowledge Innovation and Community (Climate-KIC) programme is also backing the initiative and has sponsored numerous model developers.

1.4.2 Lloyd's interest

From Lloyd's perspective – with our focus on the long-term interest of the market – our responsibilities include protecting the interests of the market and providing valued support services to members and participants. At times, this means acting as the catalyst, initiating changes that are aimed at making it easier for market participants to maintain oversight of their exposure and reduce the risk of future surprises *(Lloyd's, 2016)*.

In this instance, Lloyd's has facilitated the development of a model at the request of the market after a consultation on potential models. This has resulted in a model that evaluates earthquake risk in the Middle East.

The model, developed by CATRisk Solutions, is an example of how Lloyd's is working to provide the market support to develop valuable capacity and expertise, on a foundation of risk awareness and local expertise.

By developing a model using this approach – with managing agents' support – Oasis LMF aims to:

- Provide a choice of models that will drive down the cost of running and licensing these models
- Create transparency in models for effective use
- Create a vibrant marketplace for 'un-modelled' perils and territories
- Introduce standardisation that will create further efficiency
- Stimulate innovation
- Support shared service contracts and
- Bring new catastrophe model providers into the market

(Oasis Loss Modelling Framework, 2017b)

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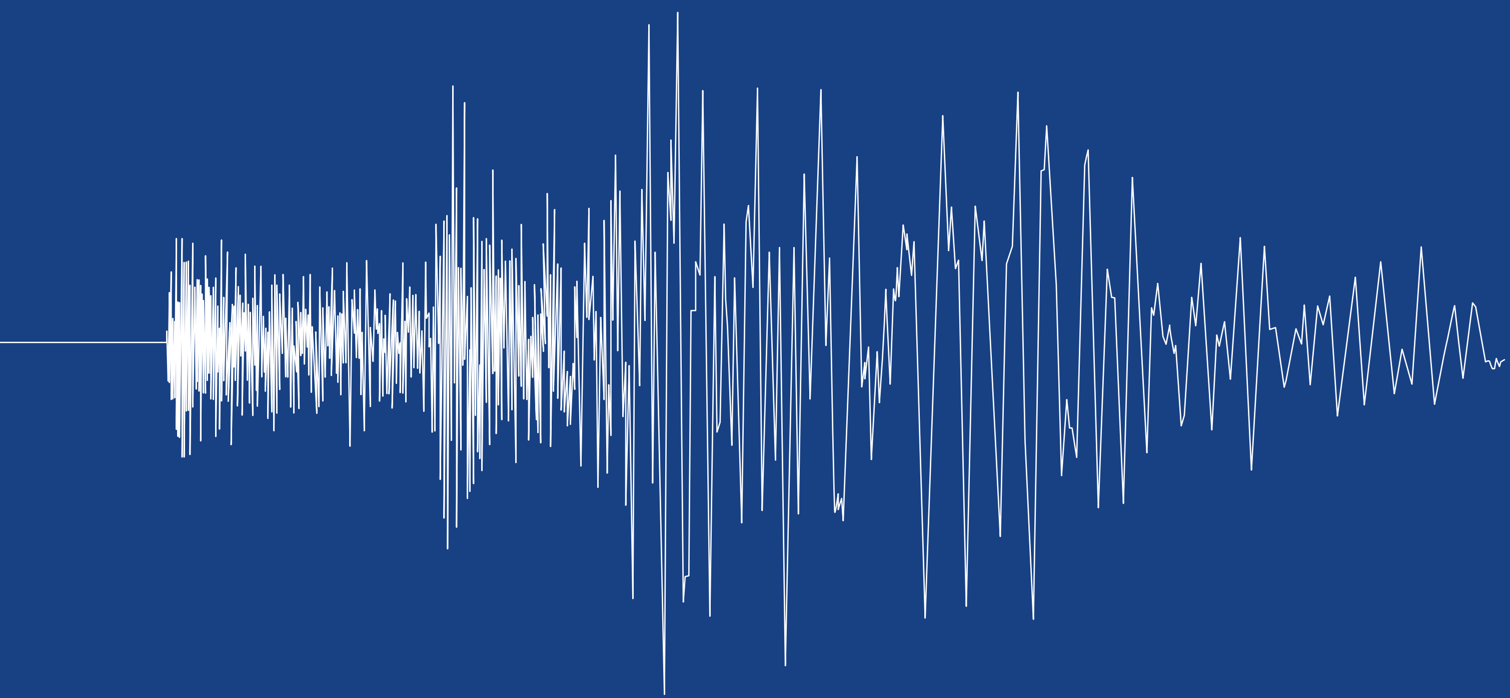
Model



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2. CATRisk Middle East quake model

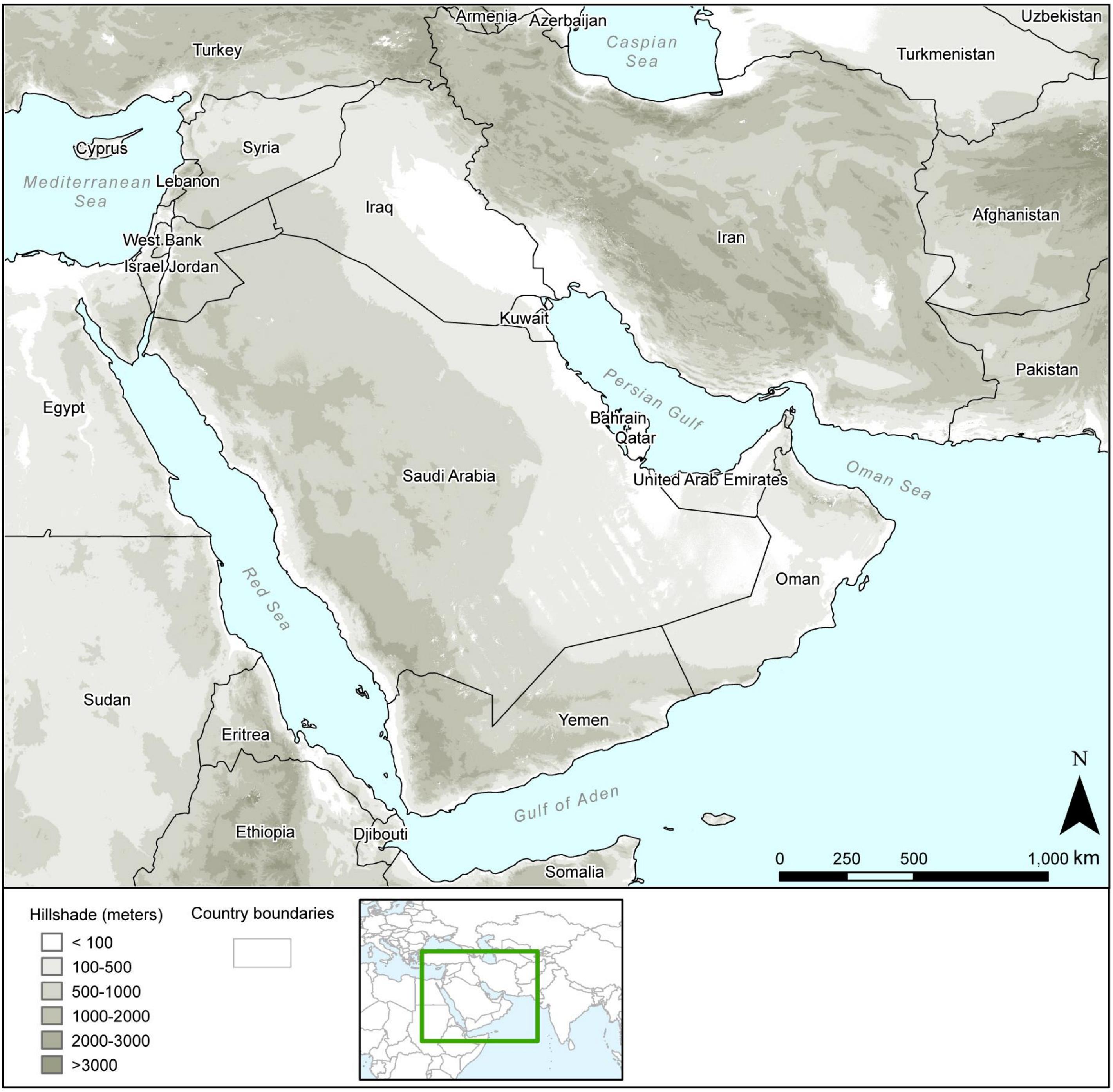
The CATRisk Middle East quake model (CATRISK-MEQM) is a stochastic earthquake loss model that covers the following countries in the Middle East region:

- Bahrain
- Iraq
- Jordan
- Kuwait
- Lebanon
- Oman
- Qatar
- Saudi Arabia
- Syria
- United Arab Emirates
- Yemen

This distinction is important as only the countries above are covered in the model, yet the wider impacts of earthquake source potential from other countries in the region has been considered in the model's hazard component.

Further countries in the Middle East may be added as the model is developed, and further scientific hazard assessments are made available. It is anticipated that this model could encourage further efforts toward collection of more detailed and reliable exposure data in the region

Figure 2: Regional overview of countries in the Middle East



Source: Lloyd's

2.1 Model components

The key model components are:

- Stochastic event sets with preprocessed hazard footprints
- Vulnerability functions; and
- An exposure-handling element

The model uses a pre-processed hazard database that provides estimates for each simulated earthquake in the catalogue. A location sampling process has also been developed at a fine scale to allow pre-processed hazard calculation to take place. This in turn allows loss calculation on an aggregated basis, as well as for site-specific risks.

The modelling framework illustrated in this study also allows consideration of uncertainties associated with the various sets of information used in the modelling process.

2.1.1 Stochastic event set

The model uses a seismotectonic source model that incorporates data on tectonic features – as well as background seismicity compiled from both historical and instrumental records – to define seismic source zones and seismogenic parameters that describe the frequency and severity of events. A detailed description of the seismotectonic model can be found in Section 3.3 (*see p26*).

Statistical analysis of sesimotectonic data within these sources allows probabilistic functions to be generated that represent spatial, temporal and magnitude components for future events.

Repeated sampling of these functions using a Monte Carlo process allows a synthetic event catalogue to be compiled that includes a large number of realistic earthquake scenarios.

Each event in this simulation process is characterised with earthquake source parameters, and where available, fault information. Events are also assigned a date to allow "Year Loss Table" (YLT) representation.

The model simulates losses in the 11 countries identified in Table 2 (*see, p29*) and the event set incorporates all earthquakes that occur in the wider Middle East region. This wider inclusion of earthquake sources is a key aspect to the model as the majority of damage may arise from earthquakes generated outside of the modelled domain.

This includes earthquakes that may occur on major tectonic boundaries, which could be offshore or in adjacent countries. For example, while no losses may be modelled for exposures in Iran, the broad extent of the seismogenic model means that the effects of earthquakes generated in this country are applicable to nearby modelled countries such as the United Arab Emirates.

Ground motion estimation is made using multiple "Next Generation Attenuation" (NGA) functions. These enable the degree of ground motion to be estimated at any point throughout the geography covered by the model. The aleatory uncertainty[d] is represented as a lognormal distribution, and is discretised in the model.

2.1.2 Vulnerability functions

Individual vulnerability functions are defined within the model for the following elements, which provide estimates of damage distributions arising from the ground-motion intensity:

- Each country
- Risk type: whether the exposure if commercial, industrial or residential
- Coverage type: building, contents or both
- Construction quality: high quality, medium quality or low quality.

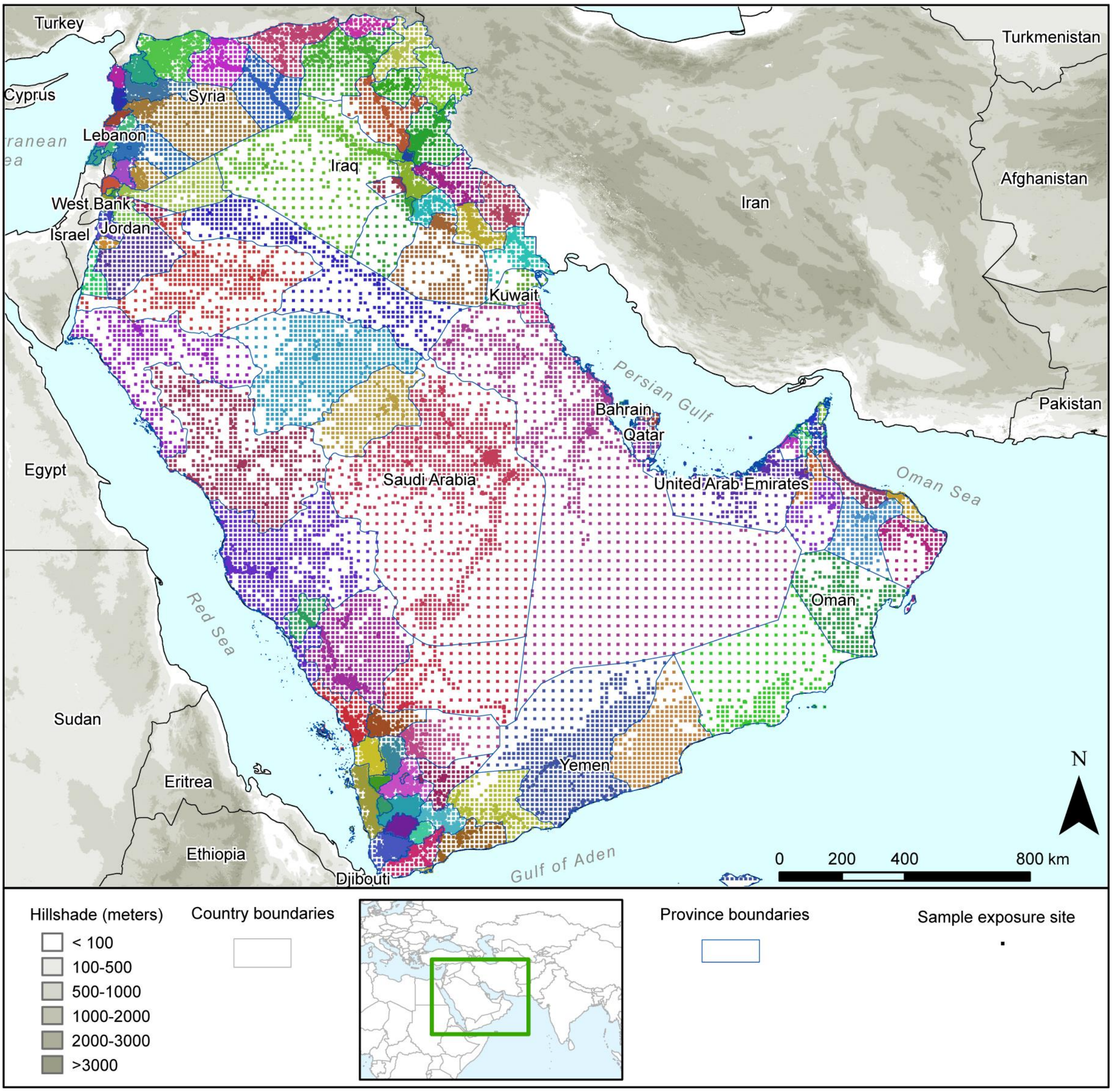
2.1.3 Exposure handling element

The hazard module for the model provides pre-processed hazard calculations on a Variable Resolution Grid (VRG). The 11 modelled countries have been divided into cells that range in size from between ~2km – ~30 km.

This process allows finer granularity of information to be represented in regions with increased exposure and data availability. By allowing this, densely urbanised areas can be represented and processed without compromising the computational efficiency of the modelling.

[d] Uncertainty due to variability or randomness, such as through dicing or flipping a coin.

Figure 3: Middle East variable resolution grid design



Source: CATRisk Solutions

Given that there is often uncertainty in the exact location of an exposure, four aggregation categories have been implemented at the following levels:

- Country
- Province
- City, and where possible
- Individual variable resolution grid cell

These aggregation levels take population-weighted average intensity distributions for all variable resolution grid cells.

The model has also been configured to provide loss estimates for individual structures. If multiple structures have been geocoded at the same location, the model can model each structure as separate entities. This feature is typically facilitated by taking an equal proportion of the Total Insured Value (TIV) for each individual exposure. There is also an option to correlate the exposures in such a way that they are all damaged by the same draws from the intensity and vulnerability distributions.

2.2 Implementation on the Oasis platform

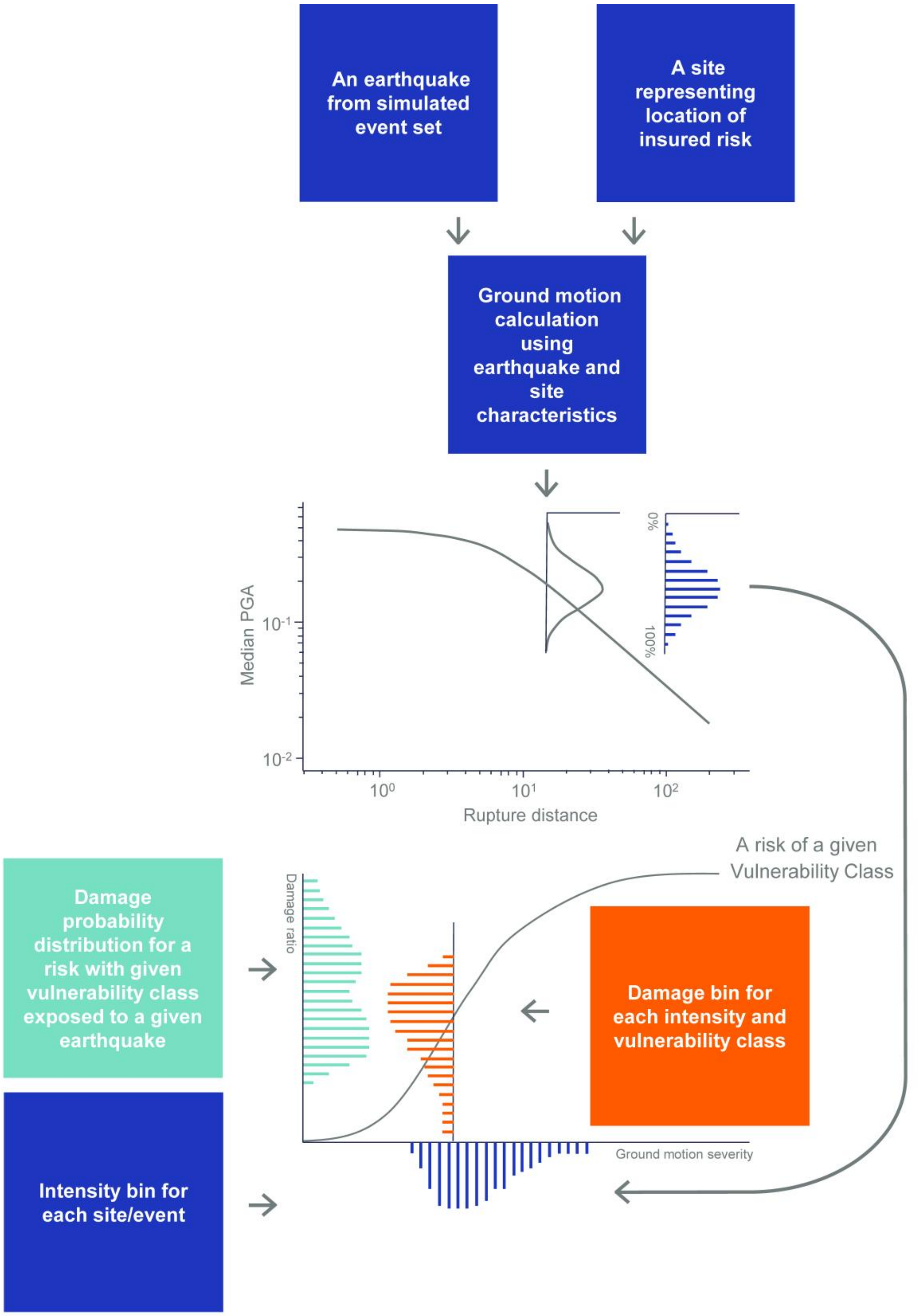
For the Middle East quake model, the hazard file represents ground-motion probability distribution for each site of interest and for each synthetic earthquake. This distribution represents the aleatory uncertainty[e] *(Alleman, 2013)* associated with empirical ground motion prediction models, known as attenuation relationships.

Another set of input data to Oasis Loss Model Framework (Oasis LMF) platform is vulnerability functions. These functions are specific to modelled building taxonomy and provide mean and standard deviation of damage against every hazard value. To allow numerical integration of hazard distribution over damage distribution, both distributions are converted to discrete distributions of chosen number of slices.

Figure 4 (*overleaf*), illustrates how these aspects are integrated using tools within the Oasis Kernel. A new distribution is generated from the numeric integration of hazard and damage distributions. This provides a damage distribution for each event and each risk.

[e] Aleatory uncertainty refers to the inherent uncertainty due to the probabilistic variability. This type of uncertainty is Irreducible, in that there will always be variability in the underlying variables.

Figure 4: Producing damage-probability distributions



This flow schematic illustrates how damage ratios are produced from event sets, site details, and ground motion calculations. The assessment of ground motion distribution for each event/site and numerical integration of ground motion and damageability distributions to derive damage probability distribution for each event and each risk.

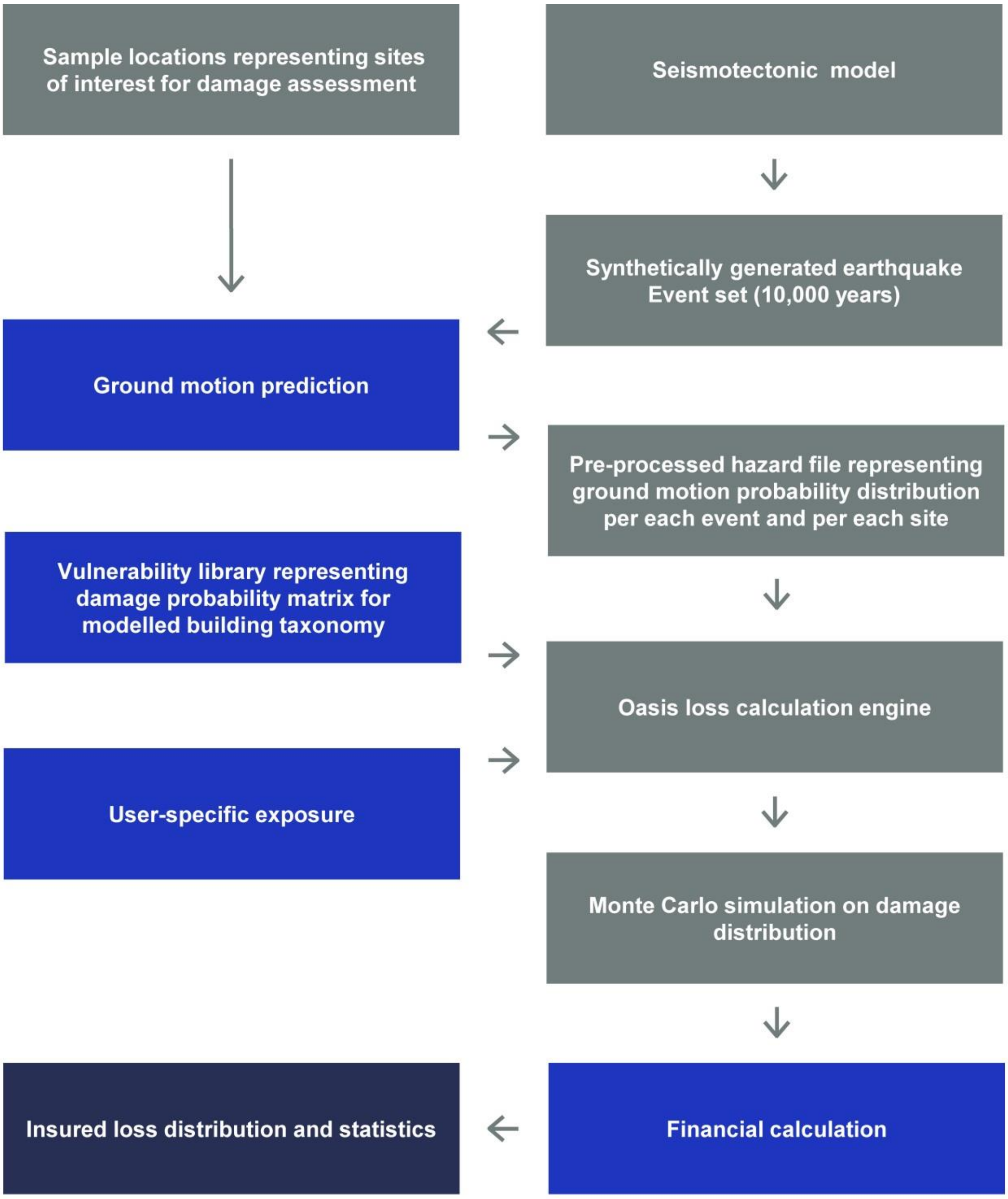
Source: CATRisk Solutions

CATRisk Solutions believes not all modelling vendors currently take this in to account, and that this process of dealing with hazard uncertainty is unique to Oasis LMF. Even if hazard uncertainties are modelled, close-form distributions are applied in order to integrate that with the damage distribution. This is regardless of the shape of damage distribution, which could be of bi-modal or multi-modal shape and is not a proxy to any known close-form distribution.

The Oasis LMF platform takes the intensity and vulnerability distributions for the Middle East quake model and combines them to produce a damage probability distribution for every single risk and each event. Expected values of such discrete distribution could represent mean and standard deviation of ground-up damage. However, further sampling of ground-up losses from such distributions, using Monte Carlo simulation, provides a framework for loss aggregation across different aggregation levels (e.g. site, policy, administrative boundary). Implementation of policy condition and financial analyses to estimate gross losses are also made possible using such Monte Carlo simulation process.

Figure 5 (*see below*) illustrates the processes of the model to reach insured loss distributions:

Figure 5**:** Project process flow chart



Source: CATRisk Solutions

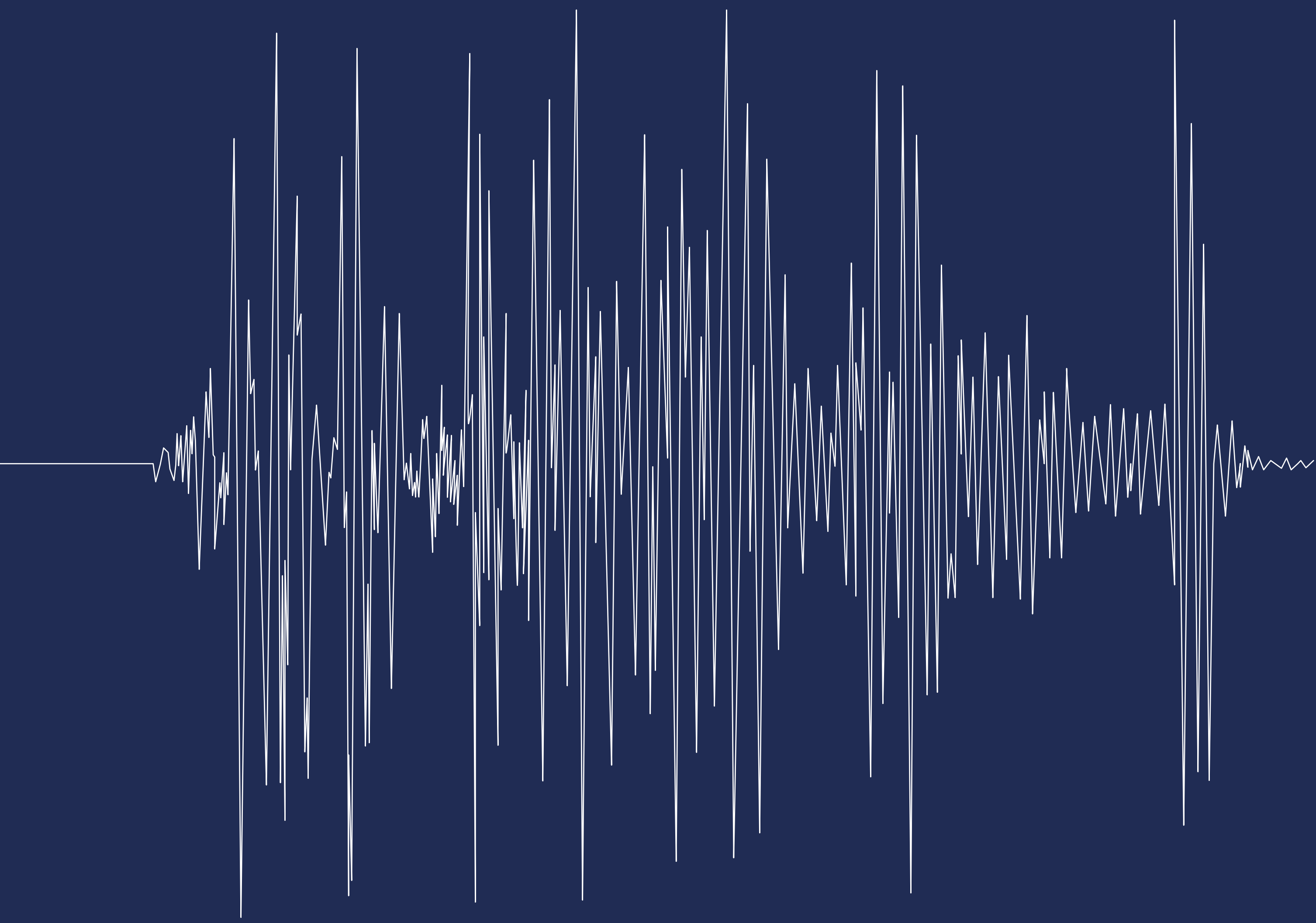
The total losses for any given event can be summed to provide overall ground-up or gross loss across a portfolio. Multiple samples can be drawn using Monte Carlo simulation from each cumulative distribution function and returned in the model output. The population average[f] and standard deviation are also returned for each exposure.

The existence of an event year mapping derived from the original Monte Carlo sampling of the seismotectonic model also means that exceedance probability curves can be produced for a given portfolio and return period losses calculated.

The ground-up losses can then be fed into the Oasis LMF financial module where limits, deductibles, layers and shares of limits can be applied by account type to provide more complex gross insured losses across a portfolio. Further processing for the application of reinsurance programmes is also available using Oasis LMF financial module.

[f] Expected value

Methodology



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3. CATRisk Middle East quake model methodology

Any attempt to model earthquake losses starts with a seismic hazard model that describes variation of hazard parameters in size, time and space in a probabilistic term. The majority of damaging earthquakes around the world happen as tectonic forces acting on tectonic plates exceed the shear strength of faults and energy is released.

These events predominately occur along fault lines, but can also be found within plate boundaries as outside stresses deforms material. Both types of earthquakes are known as tectonic earthquakes and can be considered the main sources of seismic hazards.

Because of the long timescales over which seismic activity manifests, it is important for all studies of seismic hazard that as much information as possible is sought and distilled from historical and even archaeological sources.

This is especially important for intraplate regions that have experienced few earthquakes in the 20th century, where the instrumental record may not reflect the recorded historical catalogue – notwithstanding any errors in epicentre location and magnitude estimation.

Seismic source zones are typically determined based on the relationship of observed earthquakes to tectonic features of geological units e.g. mountain ranges. The seismicity of the region, together with the tectonic features, is key information used to delineate the seismic source zones and to determine seismicity parameters as the two are closely linked. For example, oceanic ridges occur as a result of spreading plates or hotspots that create new oceanic crust; subduction zones appear as deep oceanic trenches; and the majority of mountains found on continents occur where tectonic plates are pressing against one another.

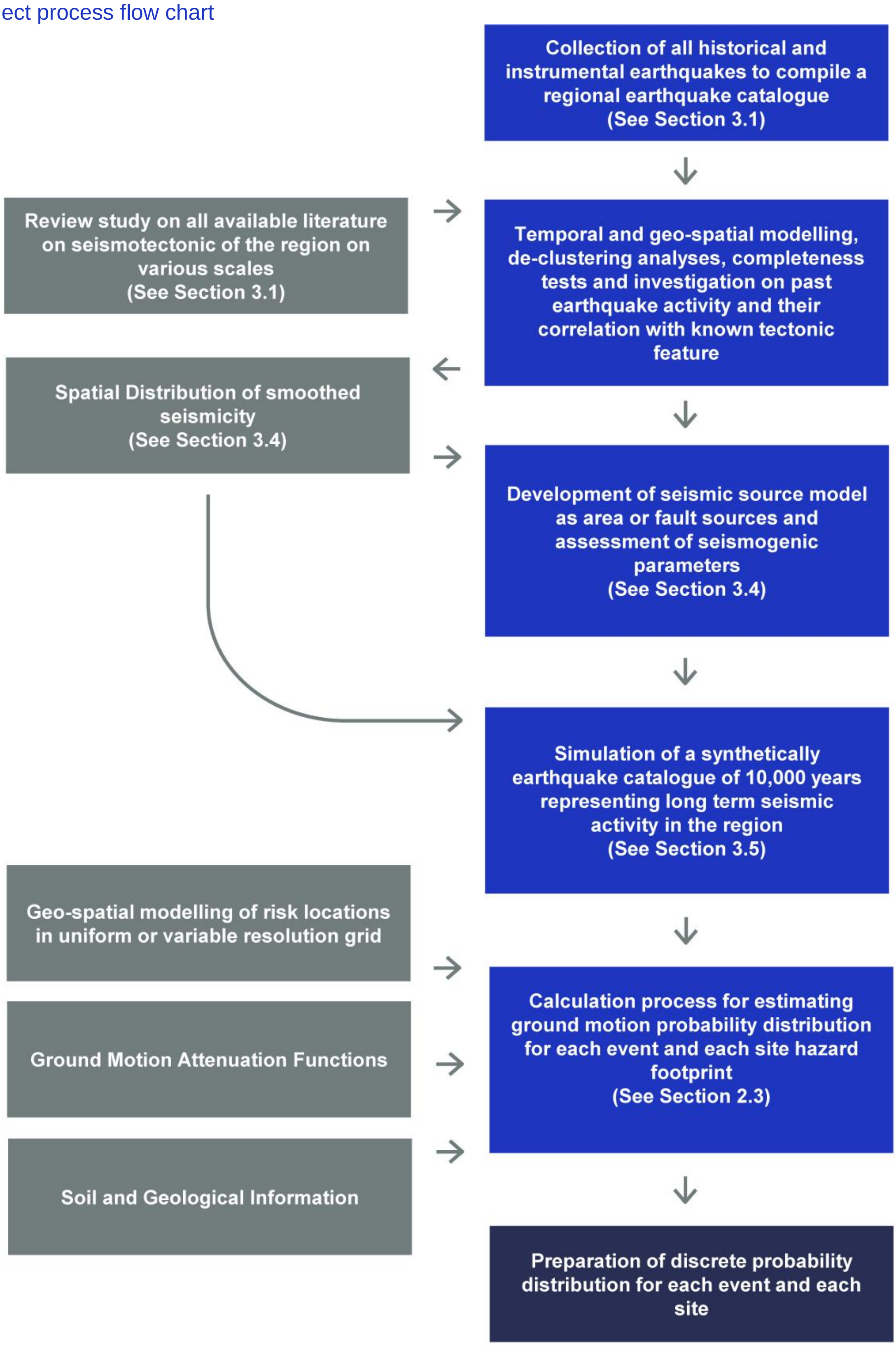
Establishing relationships between seismicity and large-scale geological and tectonic processes may also help with the identification of sources of future seismic activity.

The approach implemented in the Middle East quake model uses the latest information on past seismicity, regional tectonic deformation, location and activity of active faults and where available, slip rate measured from recent global positioning surveys. This new innovative approach allows for a full representation of future earthquakes in time and space, along with associated fault characteristics.

3.1 Methodology

Figure 6 (*below*) illustrates the processes followed in this project:

Figure 6: Project process flow chart



Source: CATRisk Solutions

The first step in a probabilistic seismic hazard assessment is the definition of earthquake source or sources which will affect the sites of interest. This step is often a key aspect central to any seismic hazard assessment, with tectonic features together with regional seismicity used to delineate seismic source zones, and determine seismicity parameters.

The geological and tectonic maps of the Middle East – as well as maps with seismic interpretation such as spatial distribution of earthquake epicentres, earthquake ruptures and seismic moment distribution – have been prepared as tools within the model to:

- Delineate seismic source areas
- Study the completeness and clustering of the earthquake catalogue
- Determine seismic activity
- Define recurrence parameters for each seismic source.

3.2 Regional historical earthquake catalogue

Seismicity in the Middle East is dominated by shallow thrust and strike-slip faults that occur at depths of less than 25km. The only exceptions are occasional and unverified shocks in the southern part of Zagros, and activity along Makran subduction zone in south eastern Iran. This activity could be attributed to subduction processes in these areas.

The earthquake catalogue compiled for this region for integration into the Middle East quake model consists of three main sub-catalogues:

1. **For pre-1900 historical earthquakes, location and magnitude has been estimated based on multidisciplinary studies of historical sources**

   Pre-1900 historical data revaluated by Ambraseys and Melville *(Ambraseys and Melville, 1982; Ambraseys, Melville and Adams, 1994)* has been used that refers to earthquakes recorded in 400BC onwards for Iran and the Arabian Peninsula.

2. **The second part of the catalogue extends from 1900 to 1963**

   During this period seismographic instruments were developed and these varied in quantity and quality, and the dataset reflects this. To counteract this, the second portion of the catalogue includes a re-evaluation of early instrumental data in conjunction with macro-seismic information *(Ambraseys, Melville and Adams, 1994; Robert Engdah, Van Hilst and Buland, 1998)*.

3. **The third part covers data for modern instrumental period which extends from 1964 to 2014**

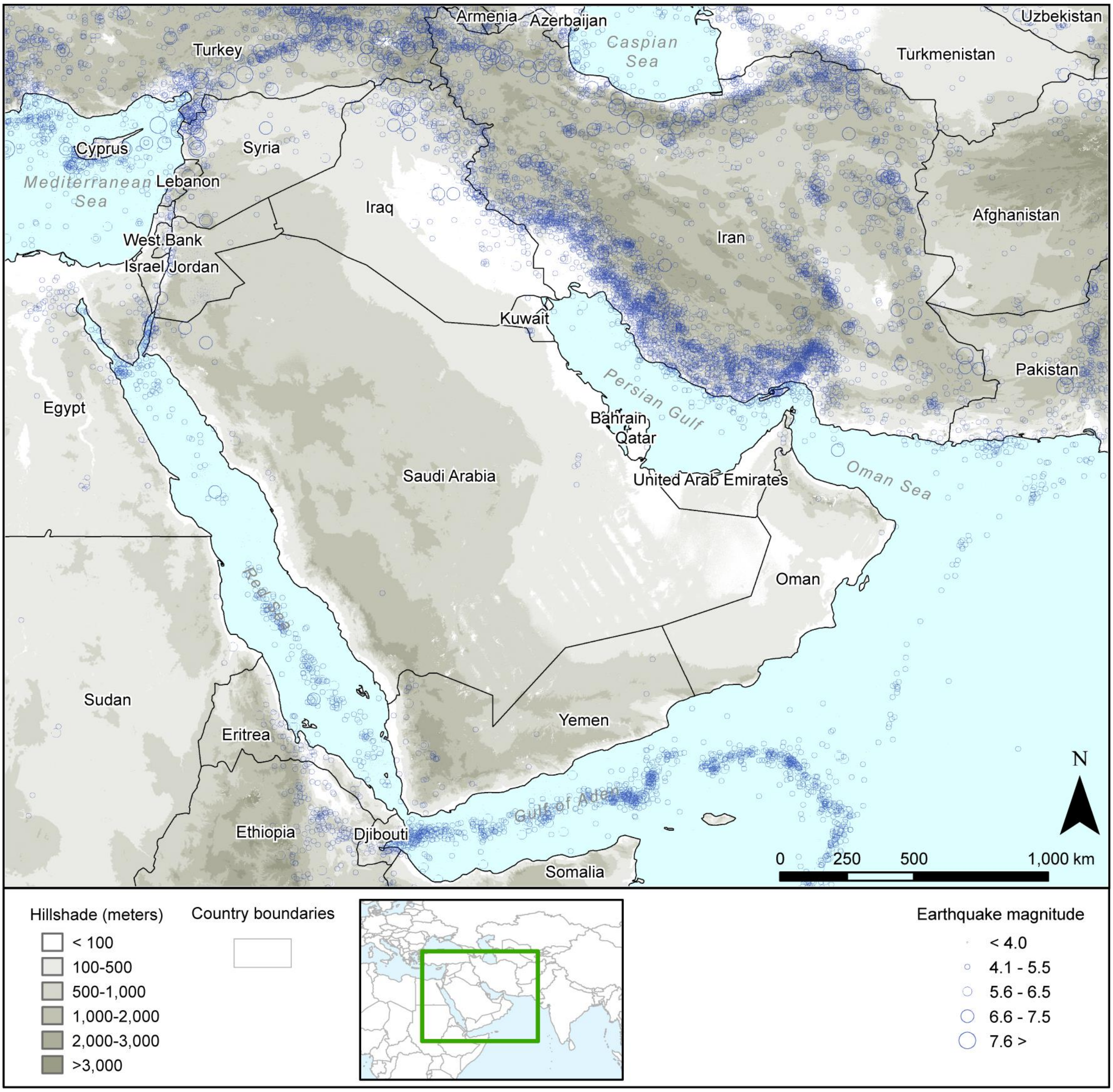
   This section contains the most consistent dataset in comparison with the other two, and includes earthquake data from the International Seismological Centre (ISC) catalogue *(International Seismological Centre, 2016)* and those from Global Centroid-Moment-Tensor (Global CMT) catalogue *(Global Centroid-Moment-Tensor, 2013; Shuler and Nettles, 2012)*. However, the catalogue also lacked consistency and completeness in time and space, and had to be further processed to examine completeness and clustering.

A sizable portion of the compiled catalogue is comprised of small to moderate-magnitude. The majority of these are dependent shocks that have predominately been recorded in the last few decades.

From 1900- 2014, countries in the Middle East have been affected by approximately 200 moderate-to-large earthquakes, which have resulted in the deaths of about 240,000 people, and affected nearly 10 million others *(Guha-Sapir, Below and Hoyois, 2017)*. These are reflected in the analysis.

Figure 7 (*overleaf*) illustrates the geographical distribution of moderate to large earthquakes from 1964-2014 for the wider region. The geographical distribution of historical and more recent earthquake epicentres shows a scattered pattern of seismicity across the Middle East region.

Figure 7: Geographical distribution of moderate to large earthquakes up to 2014



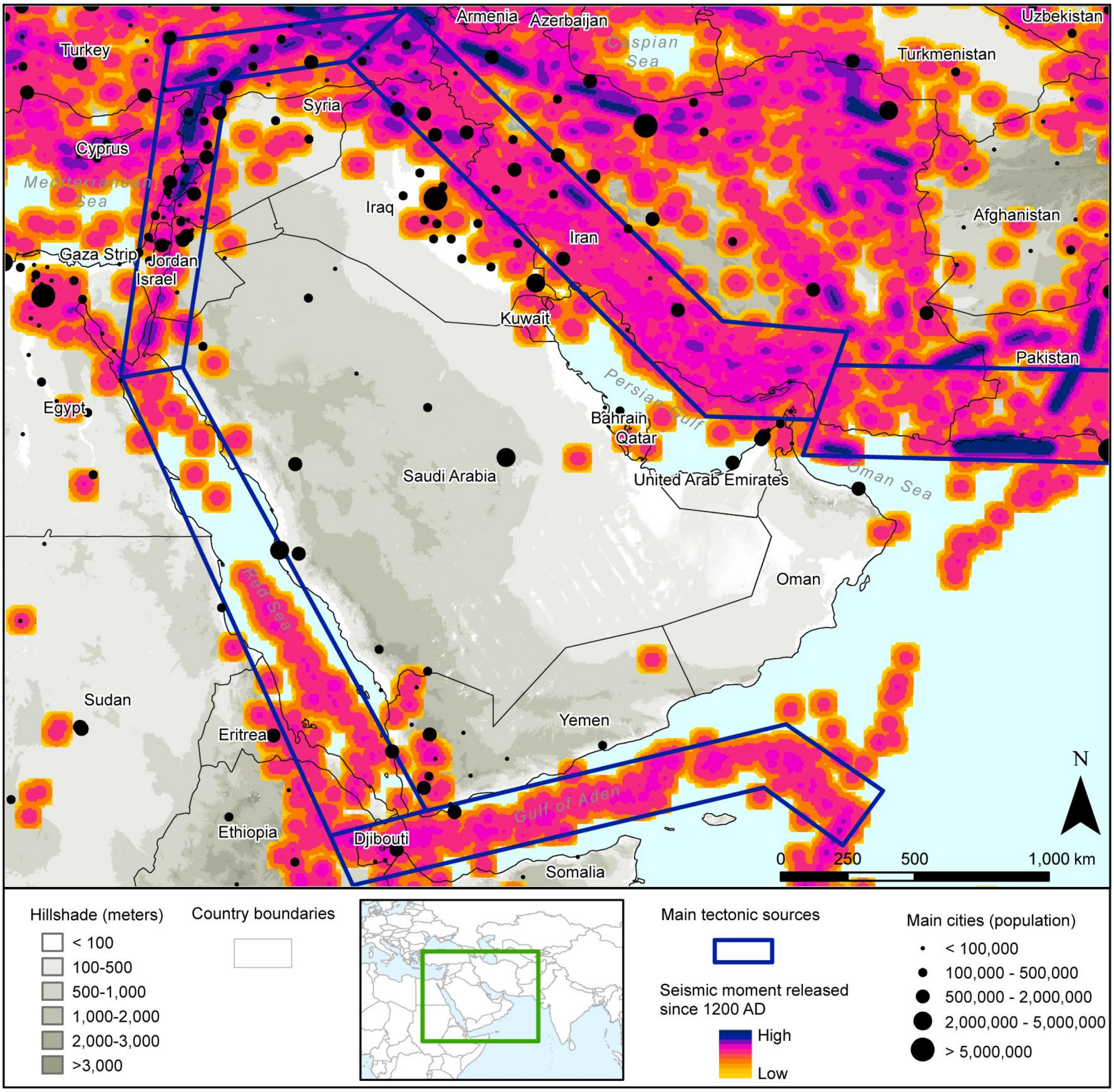
The map illustrates locations of historical and instrumental earthquakes from 1964 to 2014.

Source: CATRisk Solutions

As illustrated in Figure 7 (*above*), the areas associated with high seismic activity during the 50-year instrumental period (1964-2014) – as well as historical earthquakes – generally coincide with six tectonic zones. These zones are further described in the accompanying report “Seismic Shock: A hazard overview for the Middle East”.

Earthquake ruptures and seismic moment distributions have been prepared to illustrate the correlation between seismic activity and tectonic features in the area, and geological and tectonic maps of the Middle East. This includes maps with seismic interpretation, such as spatial distribution of earthquake epicentres. For example, Figure 8 (*below*) illustrates the distribution of released seismic energy by earthquakes in the past 12 centuries across the study region in relation to the main cities in the region.

Figure 8: Regional seismic activity since 800AD



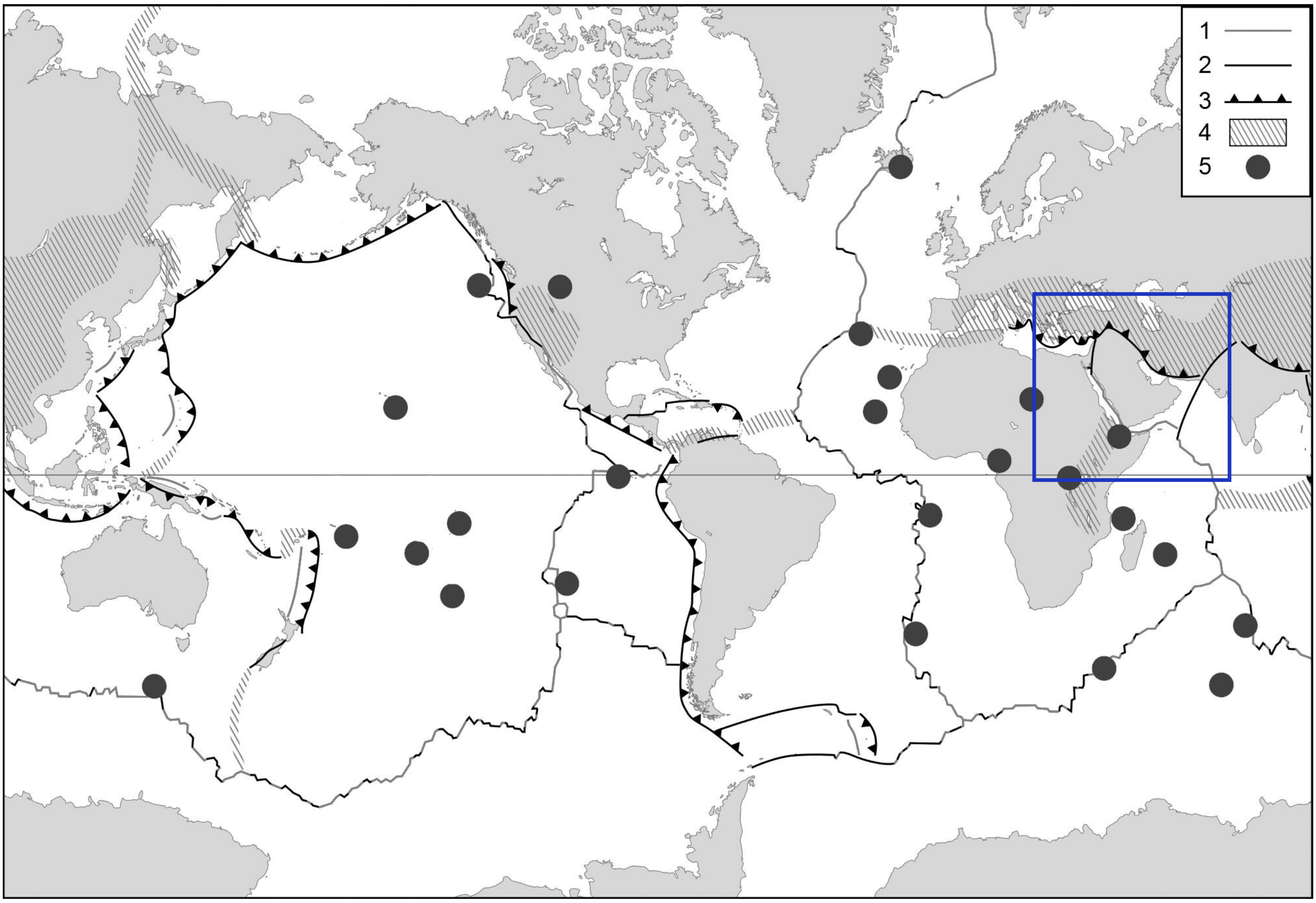
Geographical distribution of aggregated and spatially smoothed seismic moment released since 800 AD.

Source: CATRisk Solutions

3.3 Regional seismotectonic setting

Active tectonics and seismic activity in the Mediterranean-Middle East region has been shaped by the northward motion of the African and Arabian plates relative to the Eurasian plate (*see Figure 9, below*).

Figure 9: Regional plate tectonics in a world context



1: Divergent plate boundaries; 2: Transform plate boundaries; 3: Convergent plate boundaries; 4: Plate boundary zones; 5: Selected prominent hotspots.

Source: USGS

The deformation of the eastern part of the Alpine belt has been the result of shortening of the Iranian plate against the stable plates of Turan and Afghanistan. The result of this shortening is the north-eastern compression of Iran against the stable shields of Turkmenistan and Afghanistan, creating the mountain ranges seen in the cover image of this study. This shortening takes place partly by crustal thickening and partly by the lateral motion of south-eastern Iran on north-south strike-slip faults towards the Makran region *(Berberian, 1981; Jackson and McKenzie, 1984)*.

Tectonic movement along these plates has been identified and recognised by geologists for decades based on deformation seen in the geologic features of the landscape across the region. The continents are still converging and active crustal shortening can be seen occurring between these plates in recent GPS measurements *(ArRajehi et al., 2010)*. As a result, seismic activity continues in the region as the earth's crust continues to experience stresses.

The geographical distribution of past earthquakes in areas and the varied landscapes occurring as a result of tectonic deformation (*see*

Figure 7*, p24*) illustrates a varied pattern of seismicity across the region. The distribution seen over bands of 100-300km represents active tectonic deformation with high seismic activity. This coincides with the Alpine mobile belts bordering the Arabian and Indian shield masses to the south, and the Turan plate of Central Asia to the north *(Jackson and McKenzie, 1984)*.

Several large rigid blocks within the Alpine belt such as Arabian Shield, Central Turkey, Central Iran and the Southern Caspian, appear to be almost seismically “quiet” and have behaved as rigid blocks during the later phases of the Alpine orogeny[g] *(Jackson and McKenzie, 1984)*.

Low seismicity in the interior of the Arabian Peninsula suggests that little internal deformation is presently occurring in the Arabian Plate *(Berberian, 1981)*. However, these blocks are surrounded by marginal seismically active belts that in most case are not single faults but contain distributed deformation over a width of up to 400km.

The majority of earthquakes posing seismic hazard to the countries in the Middle East are concentrated along the following six major active belts illustrated in Figure 10 (*overleaf*).

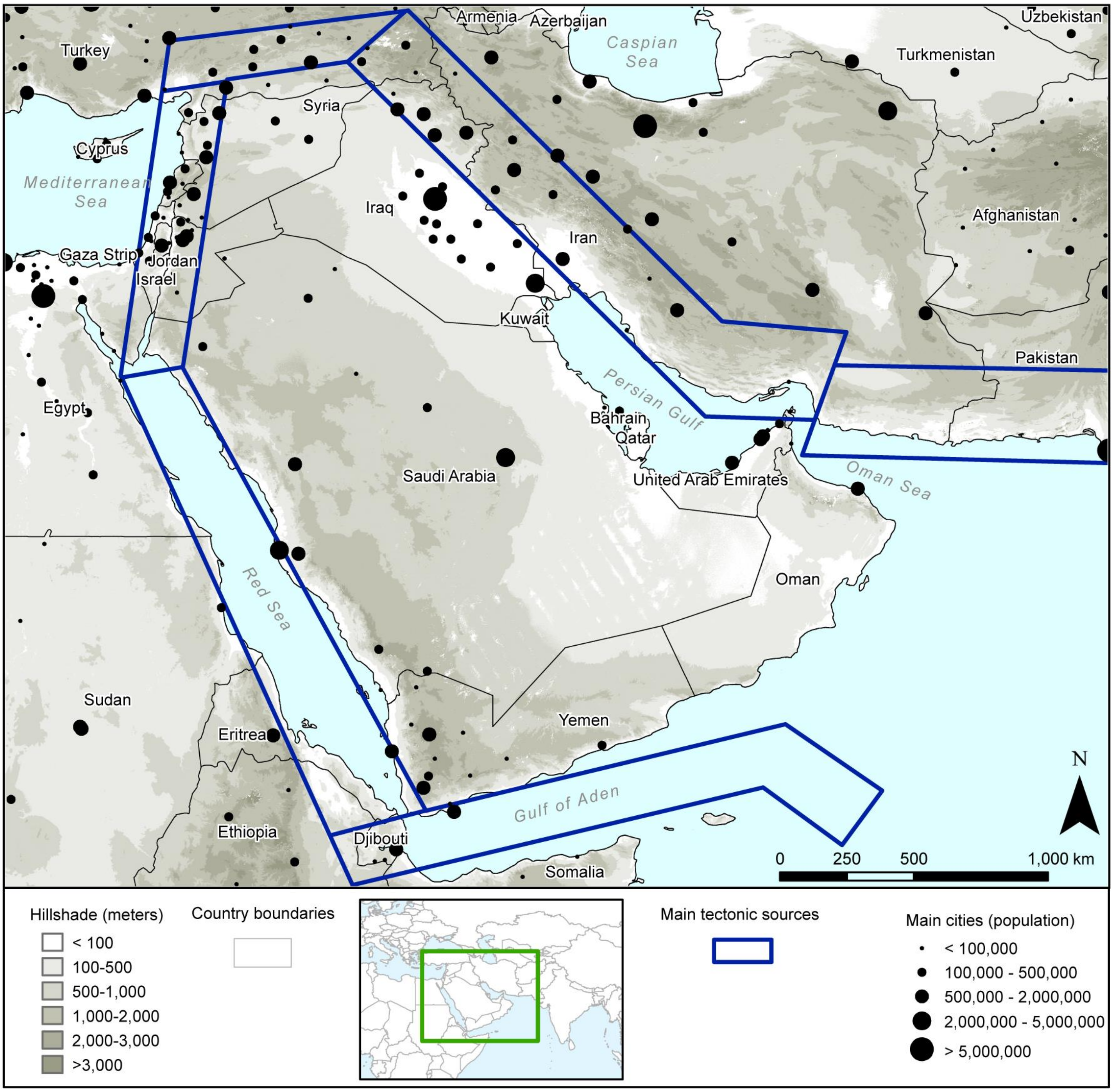
- **The Makran subduction zone:** Countries along the Persian Gulf and Oman Sea are exposed to mega-thrust earthquakes along the Makran Subduction zone which extends some 600km southeast of Iran and southern Pakistan. This region is characterised by offshore Mw>8[h] tsunamigenic earthquakes, as well as onshore moderate to large events.
- **The Zagros fold belt:** The Zagros mountain belt is a collision zone running for more than 1,500km from Van Lake in Eastern Turkey to Strait of Hormuz in Persian Gulf. This zone is characterised by frequent small-to-moderate earthquakes which account for seismic hazard to several countries in this region in addition to more than one third of Iran’s population. Most earthquakes in this zone are associated with buried faults under thick sediments, which explains the lack of fault rupture on the surface despite high seismic activity.
- **Tectonic features of Eastern Turkey and north-western Iran:** The northern boundary of the Arabian Peninsula is characterised by complex tectonic zones. One of the main features in this zone is the East Anatolian fault zone and is capable of producing M>7 earthquakes. In addition to eastern Turkey, countries such as Syria and Lebanon are exposed to seismic activity on this zone.
- **Dead Sea fault zone:** The Dead Sea fault runs from the northern part of Red Sea system to the north for almost 1,100km and forms the main source of seismic activity for countries such as Jordan, Israel, Lebanon and Syria. There have been many historical earthquakes associated with this fault, particularly the northern half of the zone. Historical seismicity and recent GPS measurements along this fault system illustrate the potential for moderate-to-large earthquakes on different segments of this fault.
- **Red Sea region:** Seismic activity along the Red Sea is associated with the separation of Africa from the Arabian Peninsula. Within the historical records, earthquakes have been recorded that have caused damage to population centres in Yemen and Saudi Arabia that have been attributed to this zone. The zone also represents the predominant source of seismic activity experienced in Saudi Arabia.
- **The Gulf of Aden:** To the south of the Arabian Peninsula, rifting apart in a similar way to the Red Sea and running in a more east-west direction, the Gulf of Aden continues the motion that has separated the Arabian Peninsula from Africa. Population centres in southern and south-western Yemen are the ones mostly exposed to seismic activity along these zones.

Figure 10 (*overleaf*), illustrates the locations of major cities in the Middle East with regard to these six main sources of seismic activity. In addition to seismicity associated to these distinct faults and active tectonic boundaries, many cities in the Middle East are also exposed to background and intraplate seismic activity associated with structural zones within the overall Arabian Shield.

[g] The Alpine Orogeny – mountain building – occurred mainly between 65 – 2.5 million years ago, although it is still active today. It saw the collision of the African and Eurasian plates, and the closure of the Tethys Ocean as oceanic lithosphere was subducted northwards beneath the Eurasian Plate, leaving today what we now know as the Mediterranean Sea *(The Geological Society, 2016)*.

[h] The moment magnitude scale can be abbreviated as MMS or written as Mw or M. The scale is used by seismologists to measure earthquake size in terms of the energy released.

Figure 10: Major cities in the Middle East and their position with regard to main sources of seismic activity



The black dots indicate the location of major cities by population in the region.

Source: CATRisk Solutions

As a result of these facts, the potential locations and magnitudes of earthquakes in these zones have a higher degree of uncertainty but their occurrence should not be ruled out and have been modelled within the Middle East quake model.

Table 2 (*below*), presents a summary overview of the key facts for the seismic regions explored in the study:

Table 2: Middle East seismic zones

Seismic Region	Main Type of Seismic Hazard	Countries Exposed	Number of Earthquakes with M≥5 in the last 50 years	Chance of M>8
The Zagros fold belt	– Strong ground motion – Landslide	– Iran – Oman – UAE – Kuwait – Irag – Turkey – Syria	N>400	No
The Makran subduction zone	– Strong ground motion – Tsunami – Landslide – Liquefaction	– Iran – Pakistan – Oman – UAE,	N<5	Yes
Red Sea region and the Gulf of Aden	– Strong ground motion	– Yemen – Saudi Arabia – Israel	N>50	No
Dead Sea Fault zone	– Strong ground motion – Landslide – Liquefaction	– Israel – Palestine – Jordan – Lebanon – Syria – Turkey	N>20	Very small
Tectonic Features of Eastern Turkey and North-Western Iran	– Strong ground motion – Landslide	– Turkey – Iran – Syria – Lebanon	N>50	Very small
Intraplate and background seismicity	– Strong ground motion	– All countries in the Middle East	N>20	No

Content based on current scientific understanding from the sources listed in the study references.

Source: CATRisk Solutions

A full description of the tectonic features can be found in accompanying technical report (*see accompanying report "Seismic Shock: A hazard overview for the Middle East", for further details*).

3.3.1 Probabilistic seismic hazard modelling

The hazard module estimates hazard footprint based on the simulation of a wide range of probabilistic earthquakes hypothesised by the seismotectonic model, which represents spatial and temporal distributions of Figure 10 (*see p28*) has been used to explain the overall tectonic characteristic of the Middle East and surrounding regions. However for the purpose of seismic hazard assessment the region has been divided into many smaller zones within the model. Figure 11 (*overleaf*) shows, for example, further division of the southern part of Zagros into many seismic sources.

Area sources

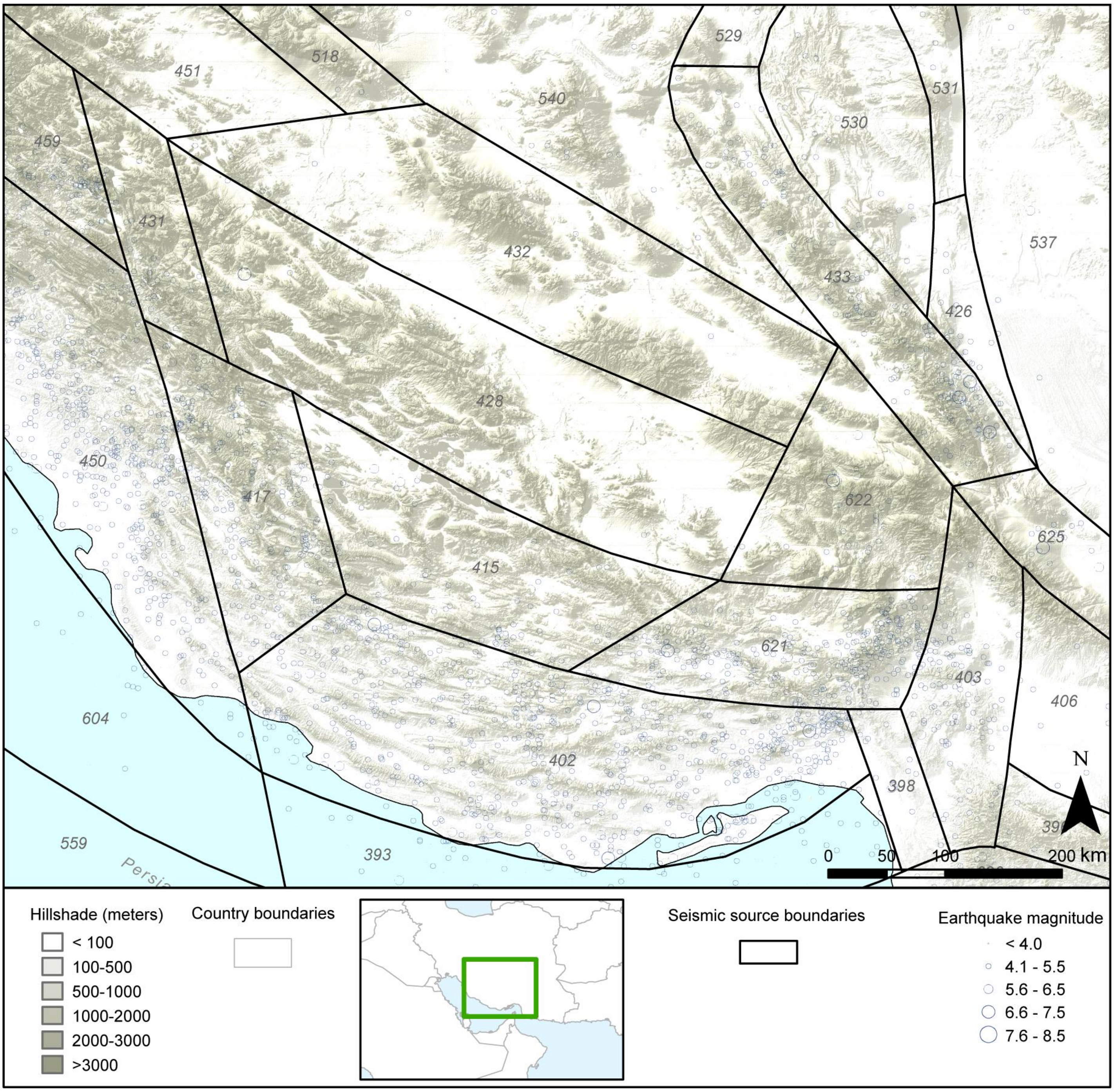
In this study the seismogenic sources are modelled by area sources based on the relationship between clustering of short-term seismic activity and the regional future earthquakes. For regions with diffused patterns of seismic activity, generated by a number of small to moderate faults, earthquake sources are modelled by area source zones.

3.3.2 Seismic source modelling

Seismic source zones are usually defined based on a combination of historical seismicity and characteristics of tectonic features. The regionalisation illustrated in

long-term tectonic movements as well as large-scale faulting activities. In addition to the earthquake epicentre maps that are often used to define source zones, other maps representing spatial and temporal distribution of seismicity such as smoothed earthquake frequency and smoothed cumulative seismic moment maps have been used. These additional maps have been used as tools to further define seismic source areas, study the completeness of the earthquake catalogue, determine seismic activity, and to define recurrence parameters for each seismic source.

Figure 11: Delineated seismic sources in the southern Zagros zone



Source: CATRisk Solutions

The delineated seismic sources are further used to test the completeness of seismicity data and to construct the frequency-magnitude relationships as well as estimation of maximum magnitude for each source. Seismogenic parameters defining the severity and frequency of future events are estimated, using statistical analyses on the historical earthquake in this region as well other tectonic information such as slip rates on major faults. Historical and instrumental earthquake catalogue is the main source of information for regionalisation and parameterisation of seismogenic source zones. The compiled earthquake catalogue described in Section 3.2 Regional historical earthquake catalogue' (*see p23*) is used in this process.

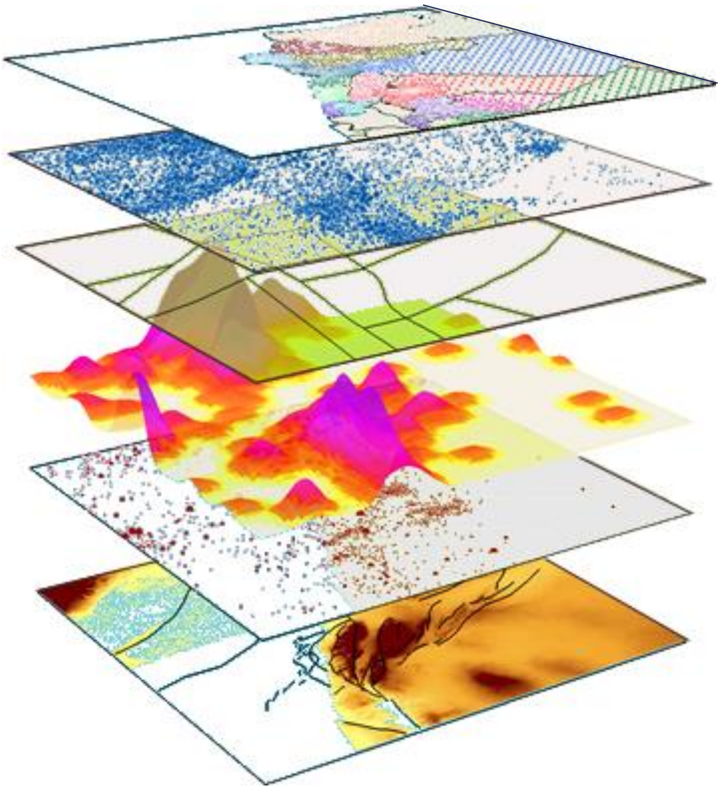
3.3.3 Simulated earthquake catalogue

Damaging ground motions in population centres can be generated as results of seismic events of different magnitudes within different seismotectonic sources. To describe a complete picture of probabilistic seismic losses, a large number of synthetic earthquake scenarios were simulated using the seismic hazard model.

For that purpose, a synthetically generated earthquake catalogue representing thousands of years of future earthquakes has been produced for the study area using Monte Carlo simulation on the probabilistic function representing spatial, temporal and size distribution of future events.

This process is illustrated in Figure 12 (*below*):

Figure 12: Monte Carlo simulation



– Geo-database of sites of interest
– Synthetically simulated earthquake catalogue
– Seismic source model
– Spatially smoothed layers of past seismicity
– Historical and instrumental earthquake catalogue
– Seismotectonic characteristics and distinct faults

The figure illustrates how synthetic earthquake catalogues are generated using various layers of geographically distributed seismotectonic characteristics.

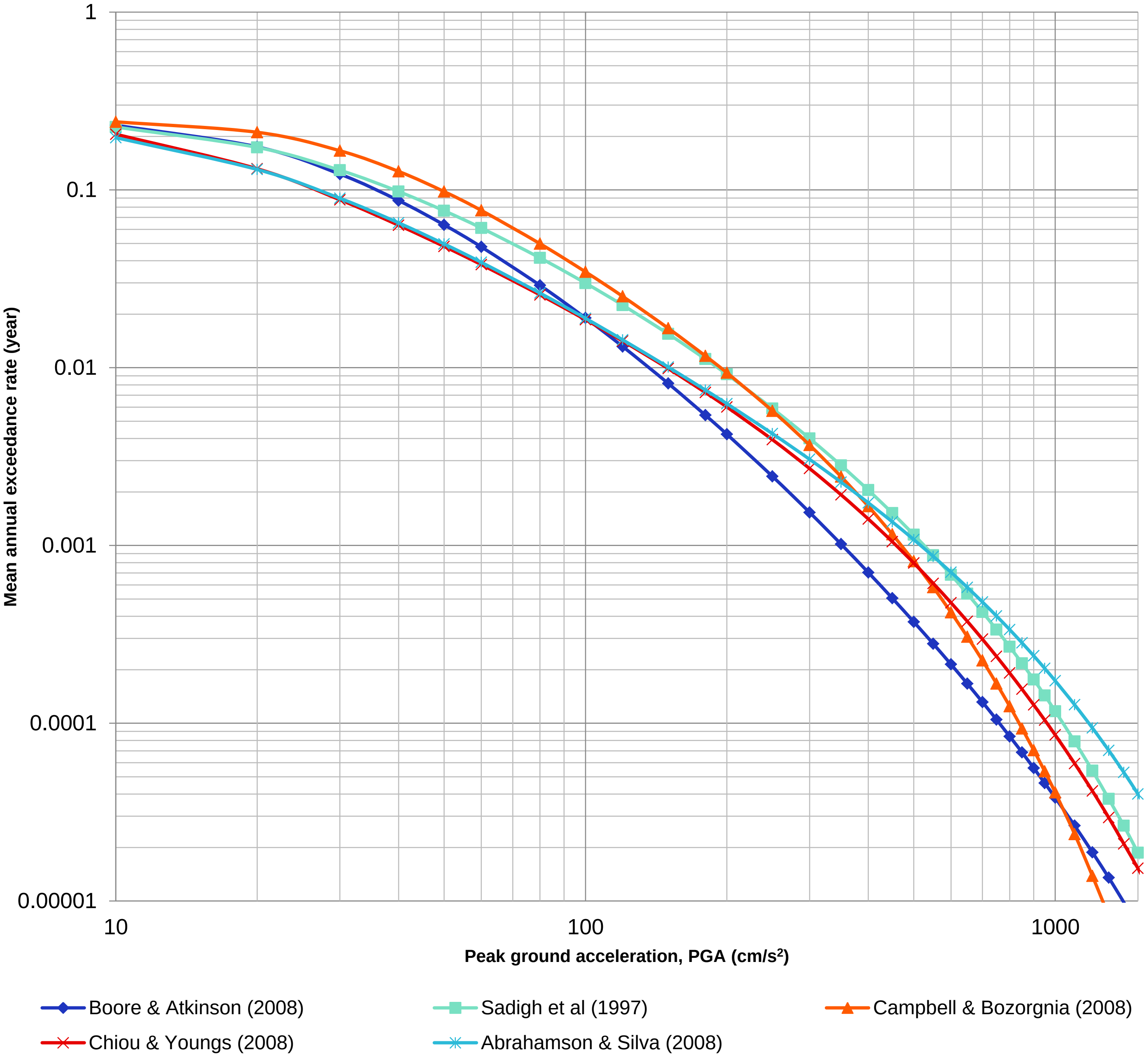
Source: CATRisk Solutions

Any exposure in this region could potentially be affected by earthquakes, ranging from small magnitude, short-distance earthquakes to large magnitude, long-distance earthquakes. Therefore, ground-shaking intensities have been estimated based on locations, magnitudes and focal depths of simulated earthquakes, using empirical ground motion equation models, known as attenuation functions.

These functions define the rate of decay of strong motion intensity away from the source of earthquake (the ability to cause damage the further away from an earthquake epicentre or starting point above the ground). These synthetic earthquakes, in conjunction with ground-motion attenuation relationships, provide probability density functions of shaking intensities at population centres.

The probabilistic seismic hazard model incorporates uncertainties associated with earthquake locations, frequencies, sizes, as well as ground-motion attenuation in order to define the severity and frequency of seismic ground motion in future. This process provides frequency distribution of ground motion for any given site, known as a seismic hazard curve. Figure 13 (*below*) shows an example of seismic hazard curves for a site in the modelled area.

Figure 13: Probabilistic peak ground acceleration for a site in the study area.



This figure is based on several ground-motion prediction models that can be found in the references section of this study.

Source: CATRisk Solutions

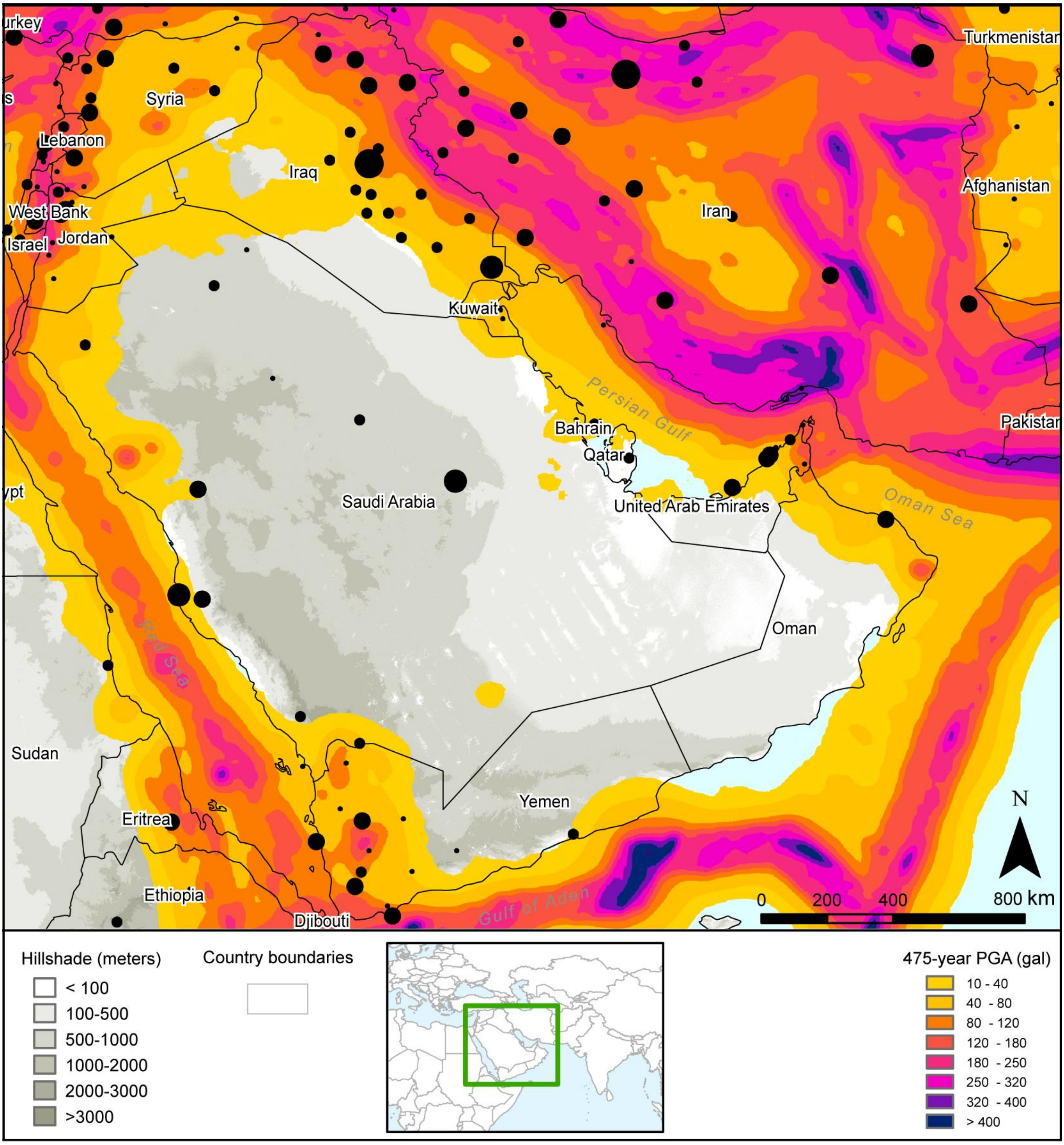
Due to the lack of proper knowledge with regard to factors controlling seismic hazards, there will always be uncertainty associated with all steps involved in developing and using seismic hazard models. While some of these uncertainties can be controlled by more accurate and reliable input data, the majority remains with large scatters and therefore, contributes to the uncertainty of the final results.

In order to account for the epistemic uncertainty associated with the choice of ground-motion attenuation function, it is standard practice in seismic-hazard assessment to make use of more than one attenuation relationship via a logic-tree algorithm.

Construction of seismic hazard curves for a set of regular or irregular points in space could be used to make probabilistic seismic hazard map, well-known and used by engineers for design purposes. The response of local soil conditions has also been modelled to reflect the amplification effect on ground motions. Several individuals and working groups have studied probabilistic seismic hazard for certain countries in this region and with various resolution and reliability in recent years. A list can be found in the reference section of this report for anyone who would like to read further on the topic.

In this study a regional and homogenous seismic hazard model is developed which covers the Arabian Peninsula and surrounding region. Figure 14 (*overleaf*) illustrates an example of such a map that represents seismic hazard map with 475 year return period – this represents a ground motion expected to be reached or exceeded with a 10% probability in 50 years is equivalent to a stationary return period of 475 years, or an annual probability of occurrence of 1/475= 0.21%.

Figure 14: Probabilistic seismic hazard map showing peak ground acceleration" for a 475-year return period[i]



The black dots illustrate the location of major cities by population in the region.

Source: CATRisk Solutions

[i] A ground motion expected to be reached or exceeded with a 10% probability in 50 years is equivalent to a stationary return period of 475 years, or an annual probability of occurrence of 1/475= 0.21%.

3.4 Values at risk

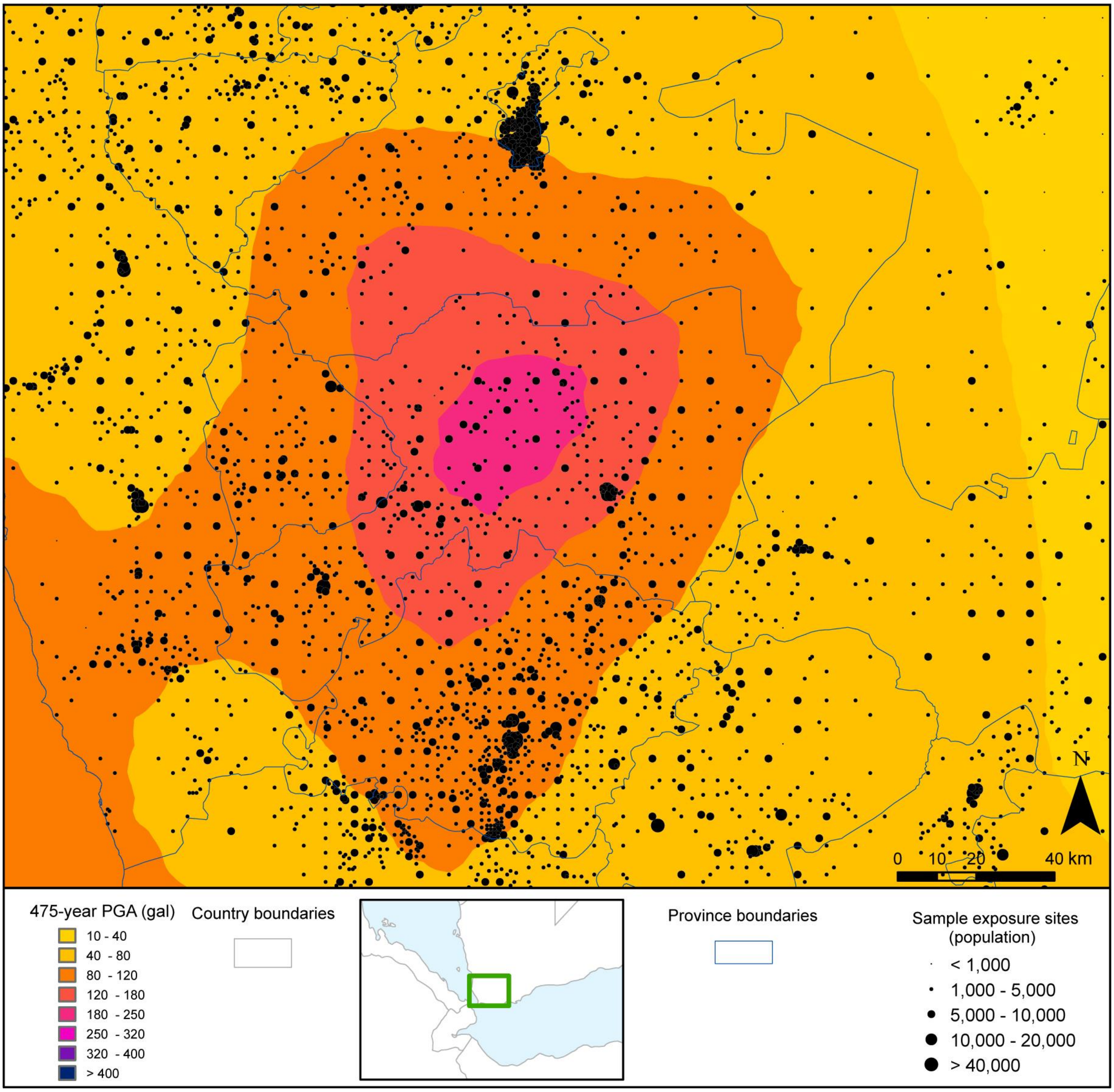
The key to improving the ability to manage earthquake risk not only depends on the reliable assessment of seismic hazard but also on risk-specific information. Such information includes the knowledge of location, structural characteristics, usage and value of assets exposed to seismic hazard.

In a well-established and mature insurance environment, this information is usually provided to a relatively detailed specification in exposure files. However, given the early stage of catastrophe-risk management in the Middle East region, the quality of collected exposure data varies significantly and may be aggregated at high level categories.

In such aggregated exposure files, sum insured values may have been aggregated for a geographic location, with no known structural and occupancy characteristics. Geographical disaggregation could be achieved by spreading sum insured values to a regular or irregular set of points representing population or urbanisation distribution.

Figure 15 (*overleaf*) illustrates a sample of such disaggregation efforts, where a variable resolution grid system has been used to distribute aggregated exposure data.

Figure 15: Variable resolution grid system sample



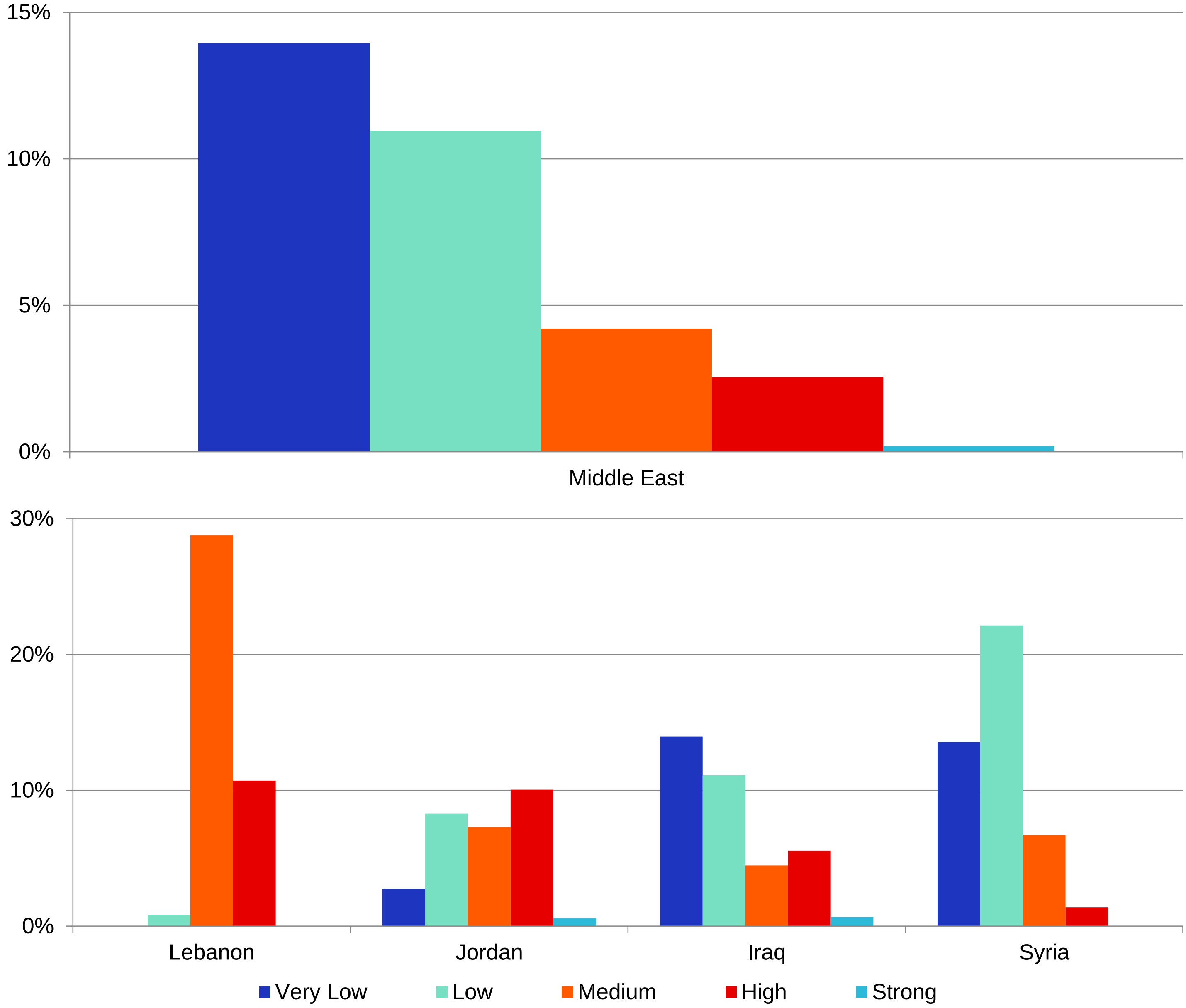
The VGR is used for hazard calculation and the disaggregation process.

Source: CATRisk Solutions

Using a simple spatial correlation of the population in the modelled countries against a 475-year probabilistic seismic hazard map[j], analysis by CATRisk illustrates that about 18% of the population is exposed to seismic hazard (*see Figure 16, below*). This figure covers exposure to ground motions with a peak ground acceleration of minimum 0.07g. Low-level ground motion at this level can cause slight damage to adobe walls and unreinforced masonry, while strong motion is capable of significant destruction to engineering buildings.

The percentage of population exposed to seismic hazards could be considered significantly higher if the more seismically active countries in Middle East, such as Iran and Turkey, were added to the model. This could be done and would require an assessment of earthquake hazard and structural characteristics for these countries.

Figure 16: Proportion of population exposed to various seismic hazard (PGA at 475-year return period)



The statistics represent at very low level ground motion (at a threshold capable of initiating slight damage to adobe walls and unreinforced masonry buildings) to strong motion capable of causing significant destruction to engineered buildings.

Source: CATRisk Solutions

[j] A ground motion expected to be reached or exceeded with a 10% probability in 50 years is equivalent to a stationary return period of 475 years, or an annual probability of occurrence of 1/475= 0.21%, covers exposure to ground motions with a PGA of minimum 0.07g and includes low to strong ground motion.

3.5 Vulnerability

Another set of input data processed in the Oasis Loss modelling Framework is the vulnerability module. This module contains vulnerability functions that should be specific to modelled building taxonomy and represents a structure's behaviour to seismic hazard.

Vulnerability functions provide mean damage ratios against ground-motion values. These ratios express the relative cost of repairs that a structure might require at a given hazard level.

The Middel East quake model has a library of vulnerability functions, providing estimates of damage distribution by ground motion parameter, and for various types of risks, classified by:

- Region
- Risk type
- Coverage
- Structural material
- Structural height; and
- Structural quality

Default functions based on regional built environment are provided for aggregate exposure with unknown vulnerability classes (*see Table 3, right*).

Table 3: Vulnerability classes available

Risk characteristics	Key	Risk type
Peril	– EQ	– Earthquake
Line of business	– R – C – I	– Residential – Commercial – Industrial
Coverage	– B – C – X	– Building – Contents – Mixed
Construction type	– ADB – MAS – TIM – CON – STL – XXX	– Adobe – Masonry – Timber/wood – Reinforced concrete – Steel – Mixed
Building height	– LR – MR – HR – XX	– Low-rise (up to three stories) – Mid-rise (four to seven stories) – High-rise (taller than seven stories) – Mixed
Building quality	– LQU – MQU – HQU	– Low quality (old building, rural, …) – Mid quality – Good quality (new building)

Source: CATRisk Solutions

Conclusion

4. Conclusion and opportunities for future development

These serious consequences of earthquake damage make it important to understand earthquake risk in the region better. For insurance to play its full potential in mitigating and transferring earthquake risk in the Middle East, insurers need better earthquake models for the region.

The model described in this report uses the latest data and new modelling techniques to provide a much-needed, additional earthquake model for the region that is different from others on the market.

This model helps insurers gain a deeper understanding of earthquake risk in the Middle East. It could help them design earthquake insurance products that are specific to the region and provides them with a greater understanding of the exposure risk across their portfolios.

Oasis: an alternative way to buy risk models

This new Middle East Earthquake model is available on the Oasis platform, which is supported by Lloyd’s. The Oasis platform offers insurers a new, lower cost way of accessing risk models on a “shared-services” basis.

This means they can access a greater choice of models in multiple regions, making it much simpler for them to obtain multiple views of a single risk.

This reduces insurers’ dependency on just one or two models, meaning they can form a deeper understanding of risks and their impacts around the world. They can then use this information to fine-tune and more accurately price insurance products.

At the time of preparation of this report, 10 Lloyd’s syndicates have made agreement with a hosting service to use the model on the Oasis LMF platform:

- Ascot
- Beazley
- Barbican
- Chubb
- RenaissanceRe
- Tokio Marine Kiln
- SCOR (Channel 2015)
- Starstone
- Sompo Canopius and
- XL Catlin

(Correct as of June 2017)

Other managing agents may participate in future arrangements for catastrophe modelling on the Oasis platform on a shared-services basis.

See www.oasislmf.org for more information.

Next steps

There are several ways in which this model and the new approach to building it could be developed further:

– Better quality exposure data from future scientific studies could be added to give a fuller picture of earthquake risk and where it would impact the region - the model's modular design means it can be updated as new scientific information becomes available.
– A better understanding of where damage could occur and the resultant losses could be gained by adding more infrastructure vulnerability metrics.
– The unique approach used by this model could be applied to model design for other earthquake-related hazards, such as tsunamis and landslides. This would allow insurers to gain a more complete picture of the risks posed by earthquake-related hazards.
– New models for perils such as wind and flood could be created using the approach used to design this model. This could create a detailed assessment of other potential threats in the region.
– It is anticipated that this model could encourage further collection of more detailed and reliable exposure data in the region.

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