



THE MINISTRY OF NATIONAL INFRASTRUCTURES  
GEOLOGICAL SURVEY OF ISRAEL

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Yariv Hamiel, Yaakov Bar-Lavi, Shacham Romach, Amos Salamon**



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## **Abstract**

Israel is situated along the Dead Sea Transform (DST), one of the most active fault systems in the eastern Mediterranean. Based on paleoseismological studies, historical accounts and modern recordings, the DST is the source of the strongest and most destructive earthquakes in the region. Given the cyclic nature of strong earthquakes ( $M_w$  6-7) the next one in this region is inevitable. Moreover, studies show that several of the DST segments have not been ruptured for a long period, suggesting the inter-seismic, quiescent term may be coming to an end. Consequently, emergency agencies and decision makers in Israel are expected to prepare for a large earthquake in the near future. One of the key elements for supporting emergency planning and hazard reduction is a loss estimation scenario, but so far only a preliminary intensity-based estimate has been made.

This work aims at adopting the US HAZUS software, a standardized loss estimation methodology, and modifying it to suit the typical conditions and parameters of Israel. The HAZUS computes site-specific loss estimations based on ground acceleration and census tracts, building and infrastructure inventories, and thus is expected to better perform loss estimations. Thus, the available demographic data, building quality data and geotechnical maps of Israel were collected and built into HAZUS structure files. Next, different synthetic scenarios of strong earthquakes in various locations were simulated. To better investigate the sensitivity of the HAZUS, the scenarios examined were run with different building-type distributions and seismic code levels.

The results show that the damage strongly depends on the quality of the buildings and the geotechnical parameters. For example, an  $M_w=6.5$  earthquake epicentered close to Sea of Galilee, is expected to destroy some tens to several hundreds of buildings, depending of course on the seismic code and the building type used in the simulations. An even more important outcome is that the expected number of fatalities and seriously injured is on the order of some tens to hundreds of people. As the current available Israeli census, building stock and the earthquake ground effects taken into consideration are only partial, the actual earthquake losses could even be higher.

The preliminary results strongly suggest that the HAZUS platform has all the advantages of being a useful tool for modern loss estimations, risk assessment and mitigation in Israel. Further use of the HAZUS will provide the Israeli civil protection

and decision-makers with indications of the areal spread, extent and type of the expected losses and thus suggest priorities for reinforcing the most vulnerable buildings. Furthermore, development of capacity and fragility curves for the Israeli building types, extension of the demographic data inventory, collection and arrangement of the data on the essential facilities, utility systems and hazard material facilities will further improve the earthquake loss and damages estimations.

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# **1. Introduction**

## **1.1 Loss estimations**

An earthquake is a sudden and violent shaking of the earth when large, elastic strain energy is released and spread out through seismic waves that travel through the body and along the surface of the earth. Up to the present, earthquakes cannot be controlled or forecasted and consequently, disasters cannot be avoided. However, there are ways to improve safety, minimize loss and injury, and increase public awareness of the risks involved. One of the most effective ways to lessen the impact of earthquake disaster on people and property is through risk assessment and mitigation. Consequently, damage and loss estimation techniques become common and are widely used to quantify potential, social and economic losses from earthquakes.

Earthquake damage and loss estimation is a complex process since it integrates several spatial parameters from different fields: 1) geology; 2) geophysics; 3) engineering geology; 4) structural engineering; and 5) demography. Despite their complexity, loss estimation studies have proven to be very useful tools for developing emergency preparedness plans and for promoting seismic risk mitigation (Agrawal, 2004).

A proper pre-planned mitigation activity cannot only save human lives but can also reduce the potential effect of disasters. Proper disaster management strategy at the initial planning level is expected to improve the overall functioning of the national emergency agencies and help to mitigate the damage effects of disaster. Loss estimates are a key tool in prioritizing the allocation of limited resources, as well as preventing the cascading of events, which can exacerbate the initial effects of a disaster. Hypothetical scenarios provide references for emergency response training exercises, response plans, and resource assessment. Effective emergency response depends on quick and precise estimates of extent of damage and magnitude. Advanced loss estimation programs can provide managers with quantitative loss projections for planning purposes, including cost benefit analysis of building codes and proposed mitigation efforts. After an event, loss estimation programs can provide answers at the critical time when the damage extent and distribution are unclear.

Most of the risk estimation methodologies have been developed in the United States over the last two decades (Vansten, 2001), with the major development being the HAZUS— a standardized loss estimation methodology. This is a widely used software, developed for the Federal Emergency Management Agency (FEMA, 1997; FEMA, 2006a,b), under a cooperative agreement with the National Institute of Building Sciences (NIBS) in 1999. The first version of HAZUS was made only for earthquake loss estimation. The recent HAZUS-MH is extended to multi hazard loss estimation (Beckmann and Simpson, 2006) and includes landslides, fires, debris, hurricanes and floods. Government agencies and researchers use HAZUS-MH for mitigation, emergency preparedness, and disaster response. The software was adopted successfully in several states in the USA (e.g., Kircher et al., 2006; Buika, 2000; Tantala et al., 2008) and recently it was even tested and adopted in several other overseas countries (e.g., Gulati., 2006; Korkmaz., 2009; Ploeger et al., 2009).

For earthquake loss estimations, once the inventories are updated and a scenario is specified, the HAZUS-MH performs a series of operations and computes site-specific loss estimations. Typically, the program utilizes equations already set within the program (outlined in FEMA and NIBS 2006b), extracts relevant information from corresponding databases and calculates the losses. The model produces quantitative estimates of the damage to buildings and infrastructures, the effect on the functionality of selected facilities, and most importantly, the impact on the population, including the number of casualties and injuries. The scope of damage can be presented in dollar-equivalent loss, including the direct repair costs for buildings and lifelines, as well as selected indirect economic losses. Functionality estimates include restoration time for key facilities such as hospitals, highway bridges, water treatment plants, electric substations, and simplified system restoration assessments for potable water and electrical power networks. Casualty estimates are provided by injury severity, and are not factored into quantitative estimates of dollar-equivalent loss. The model also estimates losses due to fires following earthquakes, and the quantity of earthquake-related debris generated.

## **1.2 Earthquake hazard in Israel**

The State of Israel is situated along the Dead Sea Transform (DST), which is a tectonically active plate boundary (e.g., Garfunkel, 1981; Ben-Menahem, 1991) separating the Arabian plate and the Sinai sub-plate (Figure 1). The DST has been generating intensive earthquake activity affecting the Israeli region, including the destructive Ms 6.2 earthquake in 1927 (Shapira et al., 1993) and the major Mw 7.2 earthquake in 1995 (e.g., Baer et al., 2008, and references therein). Thus, the DST poses a major seismic threat to the populations on both its sides, as is reflected also by the considerable peak ground accelerations expected for Israel in its anti-seismic Building Code (SI-413, 1995; Shapira and Hofstetter 2002).

Historical catalogs (e.g., Guidoboni et al., 1994; Guidoboni and Comastri, 2005; Ambraseys, 2009; and references therein) demonstrate that devastating earthquakes hit Israeli premises in the past two thousand years. Furthermore, paleoseismic studies demonstrate the occurrence of large and major earthquakes throughout the Holocene and the upper Pleistocene as well (e.g., Marco et al., 2003; Amit et al., 2002). Recurrence time for an M 6 and M 7 earthquake is on the order of  $10^2$  and  $10^3$  years, respectively (Begin, 2005; Hamiel et al., 2009). Hence, large earthquakes are expected to hit the region also in the future. As a result, Israeli cities located on or a few kilometers away from the main fault line (such as Elat, Bet She'an, Tiberias, Zefat and Kiryat Shemona) are clearly at significant risk, as are all other cities located further away.

According to the historical records, almost every major city in Israel was damaged several times in the last two millennia by earthquakes, including Jerusalem (e.g., Salamon et al. 2009; Avni, 1999) and is still vulnerable to the effects of an earthquake (Katz, 2004; Tavron et al., 2007; Salamon et al., 2009).

## **1.3 Aims of the present study**

The Inter-Governmental Committee for Earthquake Preparedness in Israel decided to adopt FEMA's HAZUS software with the aim of increasing the preparedness for a destructive earthquake in developing earthquake loss and damage estimations.

Specifically, there is an interest in improving the existing national reference earthquake scenario and assessing the damage associated with it. The updated scenario based on HAZUS will serve as a common basis for governmental and other agencies to prepare for the best emergency response after an earthquake strikes.

The HAZUS was first tested locally in Jerusalem (Tavron et al., 2007) by simulating the 1927, M=6.2 Jericho earthquake (Shapira et al., 1993; Avni, 1999). This pilot exemplified the potential of the HAZUS to forecast losses and thus help in forming strategies to reduce the impact of a major earthquake, as well as to provide the basis for rescue and relief planning. However, the HAZUS software has not yet been tested for the whole country of Israel. The aim of the present study is to develop the HAZUS platform for use in Israel, and run several synthetic earthquake scenarios along the DST. As the preliminary stage of implementation, this work aims at studying and testing the abilities and the advantages of the HAZUS platform to simulate earthquake events and estimate the expected loss and damage. The experience and understanding gained in this study will greatly help in bringing the next stages of the HAZUS to full operation in Israel.

## **2. Methodology and implementation**

### **2.1 The HAZUS software**

The HAZUS runs on an integrated GIS platform and thus provides a powerful visualization of the effects the event has on the community. The HAZUS enables focusing on the area where the most severe damage is predicted to occur, and in this way direct where mitigation efforts should be concentrated. HAZUS was designed as a series of "modules", a useful approach that provides flexibility for the addition of future loss estimation models, as new ones can be directly linked to the already developed product.

The HAZUS was originally designed for use in the United States. Yet the possibility of modifying it to non-American database structures exists and is the basis for applying HAZUS to an international setting. For applying the HAZUS in Israel, we followed the steps suggested by Hansen and Bausch (2007), a document that describes the HAZUS methodology for an international setting a regional scale.

The HAZUS methodology (Kircher et al., 1997) uses five ‘module’ analyses to estimate consequences: Potential Earth Science Hazard (PESH), Direct Physical Damage, Induced Physical Damage, Direct Economic/Social Loss and Indirect Economic Loss. Full data bases are needed for the analysis of the entire five ‘modules’. However, only limited data was available in this study (see below) and consequently it meets with level 2 HAZUS requirements (Jamieson and Milheizler, 1997), which enables obtaining preliminary loss estimates.

## **2.2 Israel – area and population**

In area Israel covers 28,240 km<sup>2</sup> and numbers about 7.2 million citizens. The area is divided into eight districts (Figure 2): the southern district, which has 15% of the total population; the Dead Sea district; the Judea and Samaria districts with 3% of the total population; the Jerusalem district that holds 12% of the total population; the central district that has 24% of the total population; the Tel Aviv district that has 17% of the total population; the Haifa district that has 14% of the total population; and the northern district that has 13% of the total population. Based on the Israeli demographic data, the entire area is divided into 3058 census tracts, with about 2355 people on average living within each of the census tracts. The highest number of census tracts per area is displayed mainly in the central and Tel Aviv districts, implying that these are the highest populated districts. On the other hand, the southern district which is a desert area, displays the smallest number of census tracts per area, meaning that this is the least populated zone of Israel. Hence, the area covered by each of the census tracts there is relatively larger than the area in the other districts. The Dead Sea district is sparsely populated and therefore was not subdivided into census tracts. Detailed demographic data of the Judea and Samaria district was not available and therefore could not be dealt with.

## **2.3 Data collection and preparation**

The development of a sound inventory base is an essential first step in the HAZUS risk/loss estimation process. As more data is collected, the results are expected to improve. For the level 2 HAZUS analysis (FEMA, 2003) the data collection and the data preparation are mainly divided into three main subjects: (1) soil condition; (2) demography; and (3) building inventory. During an earthquake event the soil

condition influences the amplitude of the passing seismic waves; thus knowing the local soil conditions is critical for assessing earthquake loss. The demographic distribution within the study area basically controls the number and size of the census tracts. In addition, specific information on the demography, such as the number of the residential population during the day and night, enables a better estimate of the casualties. The building inventory and the building classification are the basic data for estimating the damage probability (Wen-I and Chin-Hsiung, 2006) and consequently the severity of the injuries.

### ***2.3.1 Soil conditions***

The geological and seismological information are the basis for appropriate simulation, and these are usually given in broad terms, involving the location, magnitude and sometimes the rupture length. Attenuation models provide the severity of the ground motion in respect to the source magnitude and mechanism, distance to the epicenter and local soil effects. Deterministic hazard assessment calculates the spatial distribution of the earthquake ground motion that results from a given (scenario) earthquake. To determine the earthquake scenarios the present study followed the Israel Standard 413 (Shapira and Hofstetter, 2002) and used the empirical attenuation equation suggested by Boore et al. (1997).

For estimating the site effects, the present study used the site geotechnical class-map of Katz et al. (2008), which is based on the classification system recommended by the National Earthquake Hazard Reduction Program (NEHRP) (FEMA, 1997). This method is based on the average shear wave velocity of the upper 30 m ( $V_{s30}$ ) in a given site. The site classes are divided to five classes, from hard rock (A) to soft rock (E). The bulk of geological data was obtained from the geological map of Israel (Sneh et al., 1998, scale 1:200,000) published by the Geological Survey of Israel (GSI). The various geological units were correlated with the  $V_{s30}$  site-class definitions by Katz et al. (2008).

To evaluate the landslide susceptibility, the present study applied the map produced by Katz et al., (2008). Evaluation of the slope susceptibility considered the type of the geological unit, slope angle, dip and strike of the geological structure in the given site and the critical accelerations of failure. Based on Wilson and Keefer (1985), ten

susceptibility categories were defined, from the lowest to the highest correlated with ten critical acceleration steps, ranging from 0.05g to 0.6g, respectively.

It is important to note that the HAZUS computes the exposure and potential damage for the entire census tract according to the geology and the site-class at the centroid point of the tract (Tantala et al., 2008). It means that a single set of ground-motion parameters is applied to all the structures and infrastructure facilities within the given tract, regardless of how the actual ground motions and local soil conditions may vary within the tract.

### ***2.3.2 Demographic data***

Accurate and well organized demographic data is the basis for proper casualty estimations. Casualties are calculated at the census tract level. The population for each tract is distributed into basic groups of residential, commercial, educational, industrial, and hotel. The number and severity of casualties are strongly related to the extent of both the structural and non-structural building damage (Erdik et al., 2005). In smaller earthquakes, non-structural damages govern the numbers and types of casualties, whereas in stronger shakings the casualties are highly affected by structural damages, especially by the number of partially or totally collapsed structures. One of the major inputs necessary for earthquake casualty estimation is the correlation between the number and severity of injuries and the damage level of the structures. The output of casualty estimate breaks down into four severity levels of injury: 1) minor injuries; 2) serious but non-life threatening injuries; 3) serious and life threatening injuries; and 4) fatalities.

Notably, the number of casualties and the level of injury are not easily attainable due to the limited quality and lack of information in earthquake casualty data. However, several studies that established casualty rates with respect to various building types and damage levels (see next paragraph) were published during the last two decades, such as Coburn and Spence (1992) and Seligson and Shoaf (2003).

The distribution of the population in Israel was obtained from the Israel Bureau of Statistics and from the Survey of Israel, and assigned to census tracts by following the procedure suggested by Hansen and Bausch (2007). The present study focuses on simulating the daytime (2:00 pm) only, as this scenario is expected to generate the greatest amount of loss and better highlights areas of vulnerability.

### ***2.3.3 Building inventory***

A well-developed building inventory is essential for calculating damage, social and economic losses. In HAZUS (FEMA, 2003; FEMA, 2006a, b), the building inventory classification system is utilized to group buildings with similar characteristics into a set of pre-defined building classes, commensurate with the relevant vulnerability relationship classes. For a general building stock, the Structural (e.g., height); Nonstructural elements; and Occupancy (e.g., residential, commercial, and governmental) are the parameters that affect and characterize the damage and loss. Overall, the HAZUS presents four main building types: wood, masonry, concrete and steel, and these can be further subdivided into 36 classes according to the building height and seismic design level (for more details see HAZUS Technical Manual, chapter 3).

The entire composition of the general building stock within a given census tract is lumped at the centroid of the census tract, and this is where the damage-state probability of the general building stock is computed.

The building stock used in this work consists of about 902,000 buildings (Figure 3). The stock was classified according to the following types of occupancy: residential, which is about 67% of the total number of buildings; commercial and industrial (19%); religious (6%); governmental (5%); and educational (3%). The buildings were further aggregated into the HAZUS by the year built, estimated floor area, the number of stories and the seismic design level.

The HAZUS building damage functions, which are formulated as fragility curves, describe the probability of reaching or exceeding discrete states of damage for the structure and nonstructural systems. The states of the damage are: None, Slight, Moderate, Extensive and Complete. Descriptions of these damage states are found in the HAZUS Technical Manual (FEMA, 2003; FEMA, 2006a, b).

Since there are no damage functions available for Israel, the present study used the default functions given by the HAZUS for all types of loss. Regarding the building damage codes, the 36 building types and their seismic codes were classified into seven groups (Table 1). The simulations of the loss estimation were thus based on these groups, ranging from the worst-case scenario that included the URM-low code, up to the C2 -high code. These two building types set the maximal and minimal loss estimations, suggesting the actual damage should be somewhere in between. In order



to improve and perform a better and more accurate estimation of the losses, it is essential to develop the local damping, capacity and fragility curves typical for the Israeli building types.

## **2.4 The earthquake scenarios**

Seven synthetic earthquake scenarios were simulated along the DST and in the Emeq Yizre'el (Figure 1 and Table 2). The first simulation, the "Nuweiba scenario", was set at the location of the 1995, Mw 7.2 Nuweiba earthquake (e.g., Shamir, 1996; Shamir et al., 2003; Baer et al., 2008, and references therein) that shocked the Sinai Peninsula and southern Israel. Being the only strong earthquake that affected structures of modern times, the Nuweiba event seems to be the best candidate for calibrating loss estimations calculated by the HAZUS for Israel. Unfortunately, no building codes are available for Israel and the default was to adopt the codes used in the USA (with the necessary modifications). It was thus possible to compare the actual number of buildings that were damaged by the Nuweiba earthquake (Wust et al., 1997) with the computed results and select the American building codes that best resemble the Israeli style of building.

The second scenario ("Elat scenario") was set in southern Israel, close to the city of Elat. The third scenario was set south of the Dead Sea ("Southern Dead Sea scenario"). The fourth scenario was set north of the Dead Sea, close to Jericho ("Jericho scenario"). The fifth and the sixth scenarios were set close to the city of Bet She'an ("Bet She'an scenario") and the village of Kefar Barukh ("Emeq Yizre'el scenario"), respectively. The northern scenario along the DST was set within the Hula Valley ("Hula scenario"). The magnitudes of the synthetic earthquakes were set from Mw 6 to 7.2, and the fault depth, at 13 km, in accordance with the Nuweiba earthquake source parameters (Baer, et al., 2008, and references therein). Overall, the present study concentrated mainly on the Bet She'an scenario, Mw 6.5; the reoccurrence interval for such an event is every hundred to thousand years (Begin, 2005).

### **3. Results**

#### **3.1. The Nuweiba and Elat scenarios**

The Nuweiba earthquake (e.g., Baer et al., 2008. and references therein) is the only modern strong earthquake in the Sinai subplate (Figure 1) for which there is a wealth of seismic data and a good knowledge of the source parameters (e.g., Shamir, 1996). The highest ground acceleration in Elat city was estimated to be around 0.1 g (Zaslavsky and Shapira, 2000), whereby twenty-five buildings were moderately damaged and four buildings were extensively damaged (Wust et al., 1997) (Figure 4). The Nuweiba scenario is therefore very well suited for calculating loss estimations and comparing the calculated results with the actual losses that were documented after the earthquake.

The simulated PGA of the Nuweiba earthquake around the city of Elat ranges from 0.05 g to 0.073 g, whereby the highest value is located in the eastern part of the city, around the hotel zone. The high PGA may be the result of the thick unconsolidated sediment sequence (Zaslavsky and Shapira, 2000).

The number of buildings that are expected to be damaged, according to the HAZUS scenario, is based on the different combinations of the building-type and codes (Table 1 and Figure 4) and is classified to three damage levels: 1) moderate severity level, which in this case ranges from 7 to 65 buildings (URML to C2H codes, respectively); 2) an extensive severity level where the number of the buildings that are expected to be damaged in Elat goes from 0 to 10; and 3) complete severity level, which points to no more than one building. Comparing the above scenario with the actual number of the buildings affected, then the 'moderate severity level' falls within the lower range of the calculated number; the 'extensive severity level' fits within the middle range; and in the 'complete severity level' there was no actual number of buildings affected. In addition, only one person was expected to suffer severity 2 injuries.

Elat is the most densely populated city along the DST in the Southern and Dead Sea districts (Figure 2) and the importance of running the HAZUS platform for loss estimations should not be underestimated. The "Elat scenario" shows that the number of buildings that are expected to be completely damaged is on the order of several and up to hundreds, depending on the earthquake magnitude and the building-type codes (Figure 5a). In parallel, the number of the expected 'extensively damaged' buildings

ranges between several tens and up to several thousands. Most importantly, the number of fatalities is between several up to hundreds of people (Figure 5b).

### **3.2. Central and northern Israel earthquake scenarios**

The Southern Dead Sea area and Jericho are sparsely inhabited and, in addition, the data for this region is partial (Judea and Samaria districts), although the several attempts done here show that loss estimation in these areas is certainly possible. Therefore, most of the effort done here concentrated on the northern districts, where the area along the DST is more populated and the data inventory is fuller.

Of the three northern scenarios, Bet She'an, the Hula and Emeq Yizre'el, the first seems to be the most important. The city of Bet She'an and the surrounding area is the highest populated area along the DST in northern Israel. According to the Israel anti-seismic Building Code 413, the expected PGA values are higher than those in Emeq Yizre'el; and the Bet She'an valley is covered by soft sediments of Vs30 class-unit D, making this area highly risky.

The results show that for an earthquake of magnitude 6.5 Mw close to Bet She'an, the number of buildings expected to be completely damaged is tens to hundreds and more, depending on the seismic code and the building type that are chosen (Figures 7 and 8). The number of the buildings expected to be extensively damaged is between hundreds and thousands, whereas the number buildings expected to be moderately damaged is between thousands and tens of thousands.

Accordingly, the number of people who are expected to be fatally injured ranges from several to tens, or hundreds, depending on the chosen casualty rates. The number of people who are expected to sustain severity 3 injuries is several to tens or hundreds of people, respectively. Similar orders of demographic loss and building damage were obtained also for the "Hula scenario" (6.5 Mw).

The excellent ability of HAZUS to resolve the expected damage by specific census tracts and different damage categories as seen here (Figures 7, 8 and 9), seems to be very promising. A closer look at the epicentral area shows that 742 buildings are expected to be completely destroyed (Figure 7a), whereas farther away, in the 19 towns and villages around Bet She'an, only five buildings are expected to collapse. Furthermore, examining three different census tracts in Bet She'an, shows that each

neighborhood would be damaged differently (Figure 9b). Similarly, damage in the villages and the city in the Nazareth zone, 35 km farther away from the epicenter, also differs according to the various damage categories (Figure 9c).

Analysis of the coastal "HaHof" zone (Figure 9a), 65 km away from the epicenter, shows that the number of the damaged buildings is similar to that in places that are only about 20 km from the epicenter (Figure 9d). This may result from a local site effect that increases the damage, even though the distance from the epicenter is longer. For example, in Kefar Yona, 60 km away from the epicenter, 90 buildings are expected to be damaged moderately and 20 buildings are expected to be damaged extensively, while similar numbers are obtained also for villages that are much closer to the epicenter.

Moderate to strong earthquakes generate landslides (Keefer, 1984; Owen et al., 2008) that may cause injury, damage buildings, block roads and disconnect towns and villages from essential supplies and ground transportation, etc. Hence, estimating potential locations where landslides may occur is an important factor in emergency response. The HAZUS is capable of simulating the expected ground accelerations and comparing them with the landslide susceptibility maps in order to identify places vulnerable to slope failure (Figure 10a). For example, the "Hula scenario" indicates that the PGA about 35 km northeast of the epicenter is expected to be above 0.12 g (Figure 10b). This area is vulnerable to slope failure and this is also where the road passes that connects the Deir El Asad village to the major road. Thus the HAZUS is able to pinpoint the exact place where an important transportation line may almost certainly be blocked (Figure 10c) after such an earthquake.

Estimations of the economic losses may be an important tool for decision makers in deciding where to invest the limited time and resources available ahead of time before the earthquake, as well as right after it. Several types of economic loss can be estimated such as: loss of a general or a specific building type; loss of a general or a specific occupancy; loss of structural or non structural damages; loss of building content; and loss of income.

Direct economic losses due to the "Bet She'an scenario" show that the total may reach to several billions of US dollars (Figure 11a). This estimate can be further resolved into specific subjects. For example, the total direct economic loss for educational buildings is on the order of several million US dollars (Figure 11b), the direct loss

without time restoration and loss of building contents may be on the order of one billion US dollars (Figure 12a). Depending on the area scale, the analyses indicate that the losses far from the epicenter could reach to 465 million US dollars (Figure 12b) and close to the epicenter, to 340 US dollars (Figure 12c). As mentioned above, each of the neighborhoods within the Bet She'an city is expected to undergo a different level of damage. For example, the total direct economic loss of the Eliyhu neighborhood, without time restoration and loss of building content, is estimated to be about 82 million US dollars (Figure 10d).

#### **4. Conclusions**

Earthquake assessment may be separated into two functional steps (Korkmaz, 2009): 1) rapid visual inspection; and 2) detailed evaluation. Most modern and advanced sophisticated software platforms that model loss estimations are designed to calculate detailed evaluations. Yet for this, detailed and well-organized data are required, the obtaining and processing of which can take years. The transition from the stage of rapid visual inspection to the stage of detailed evaluation may be the hardest work, because it requires convincing the authorities about the importance of such a step, starting collection of the data and simultaneously implementing the appropriate software platform. The experience gained in this work, namely the data inventory presented here and the preliminary use of the HAZUS, indicates that the State of Israel places somewhere in between the two stages. Nevertheless, even though the stage of detailed evaluation has not yet been fully achieved, the benefits of a basic use of the HAZUS platform, as described here, proved to be fruitful and useful. As the next strong earthquake is inevitable and may strike Israel at any time, which unfortunately cannot be predicted, there should be no hesitation in the implementation of the HAZUS (or any other similar) platform.

For a Mw 6.5 earthquake with recurrence time of several hundred years in each of the DST segments, the present results indicate that the number of poor quality buildings expected to be totally destroyed could reach to more than one thousand and the number of casualties could reach to several hundreds. On the other hand, for high quality structures, the number of buildings expected to be totally destroyed could reach to several tens only and the number of casualties could reach to several or a few

tens. The simulations also show that the damage strongly depends on the geotechnical parameters of the exposed rocks in the site.

Clearly, the present loss estimations should not be taken as fact value, but rather as a rough estimate of the scope of expected damage and its areal spread. Certainly, the data inventory should be completed, demographic data improved, quality building codes should be calibrated to better reflect the Israeli standards, and earthquake source parameters more accurately defined, including the rupture along a fault line rather than a single point, directivity effects, etc.

Overall, it appears that the HAZUS platform has all the advantages of being a useful tool for earthquake loss estimations in Israel, both for future events as well as for immediate response after an earthquake occurs.

The losses estimated from the Nuweiba scenario show that the calculated number of damaged buildings falls within the range of the actually observed damage (Table 1 and Figure 4). Nevertheless there is urgent need to determine the quality codes typical to Israel.

Yet even though not calibrated, the potential benefits of the HAZUS stretches over a wide spectrum of abilities such as: 1) computing the number of expected damaged buildings according to different severity levels (Figures 4, 7, 8 and 9); 2) calculating the number of the expected injuries and casualties by different severity levels (Figure 5b); 3) evaluating the different direct economic losses (Figures 11-12); and 4) identifying places of high risk for landslides (Figure 10).

It has also been shown that the HAZUS is capable of supporting and directing decision-makers and emergency authorities in identifying vulnerable structures before an earthquake occurs, and thus take the necessary steps in order to mitigate and reduce the expected losses. Equally important is directing the protection authorities in timely, focused and proper response to an earthquake that has just happened (e.g., Figure12). The HAZUS is able to show the severity, type and extent of the losses that occurred, and where they took place.

The HAZUS abilities for simulating losses and damages before and after earthquake events in Israel are conclusive. Yet there are several necessary development steps that should be taken in order to improve the existing HAZUS database, the most important of which are:

1. Developing capacity and fragility curves for the Israeli building types, in accord with the HAZUS platform demands.
2. Extending the demographic data for giving estimations of injuries during different times of the day, estimations of the shelter needs and simulating indirect economic losses.
3. Collecting and inputting the data on the essential facilities such as hospitals, electric power stations, pumping stations, etc.
4. Collecting and inputting the data of the utility systems such as water, gas, electricity, communications and others.
5. Collecting and inputting the data of hazard-material facilities.

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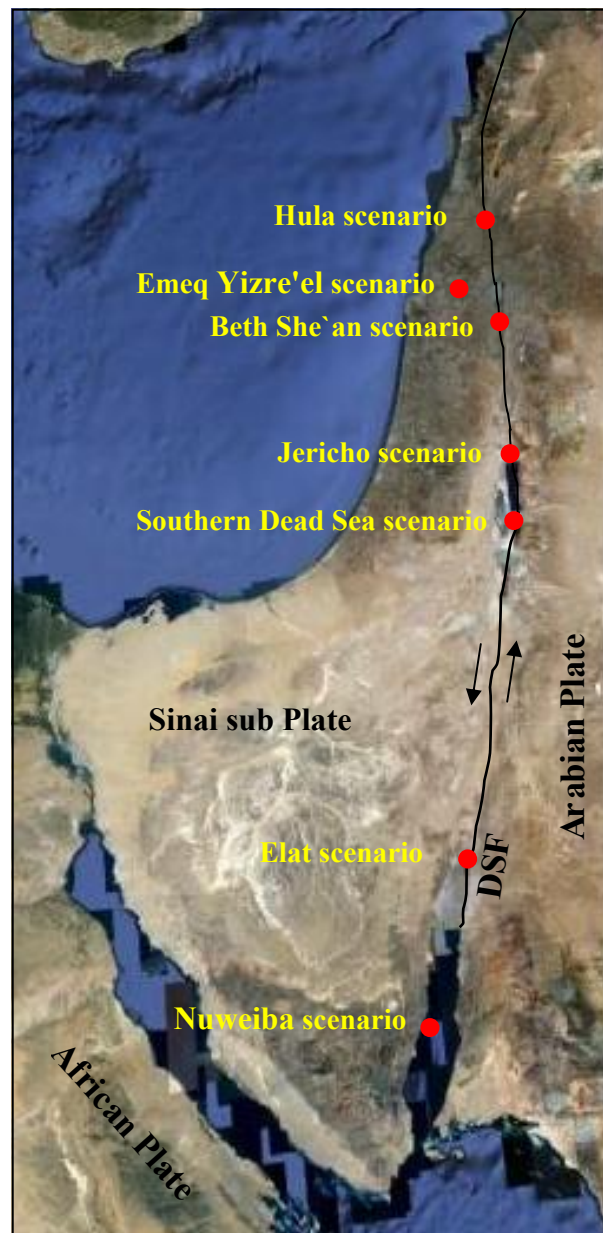
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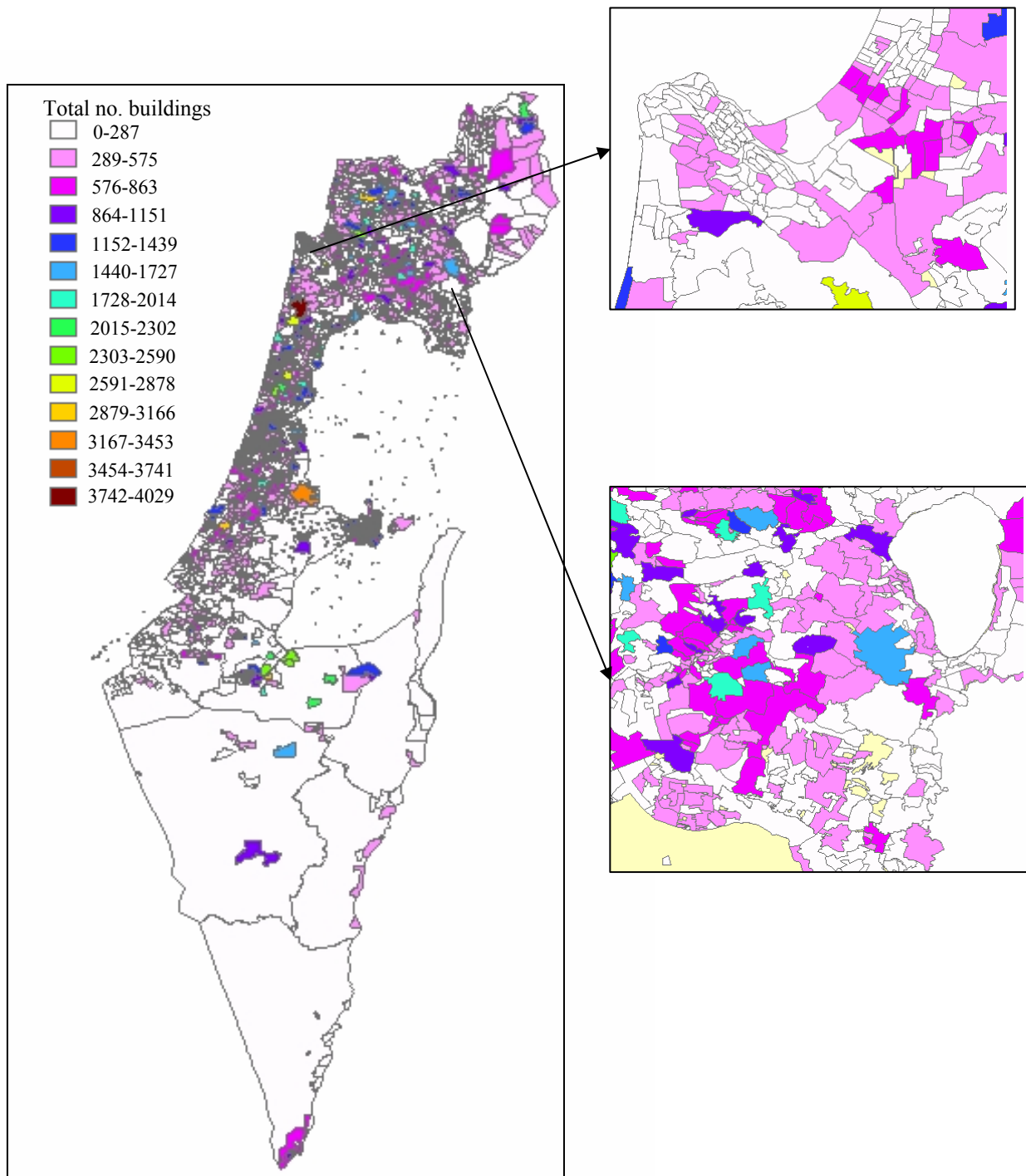
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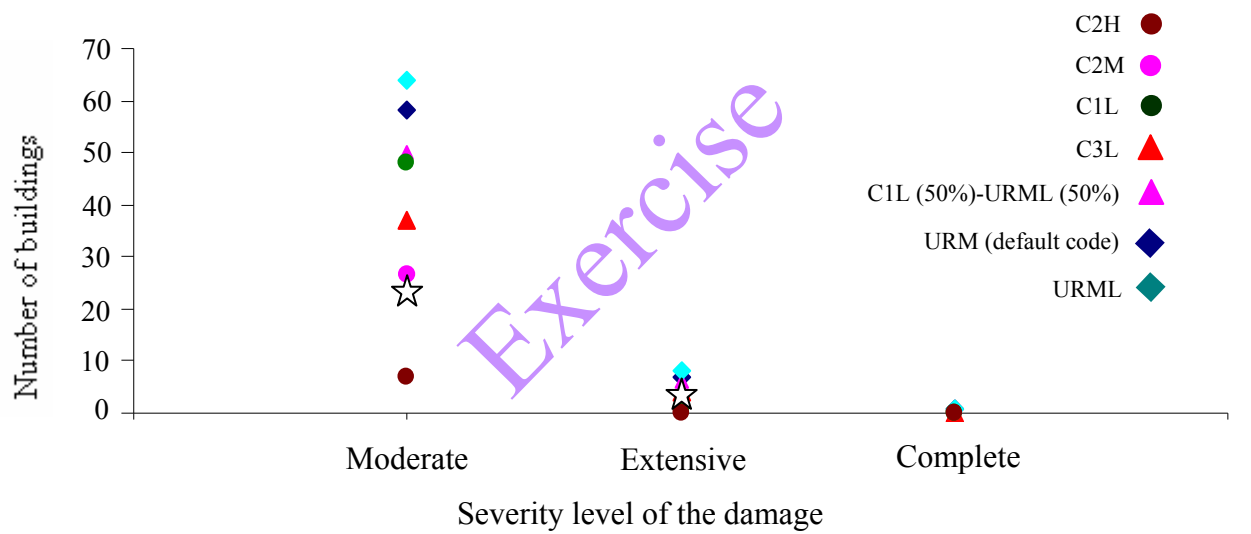
**Figure 1:** Location map of the study area showing the regional setting of Israel and the seven synthetic earthquake HAZUS scenarios (red circles). The seismogenic Dead Sea Transform (DST) is marked schematically by a black line.



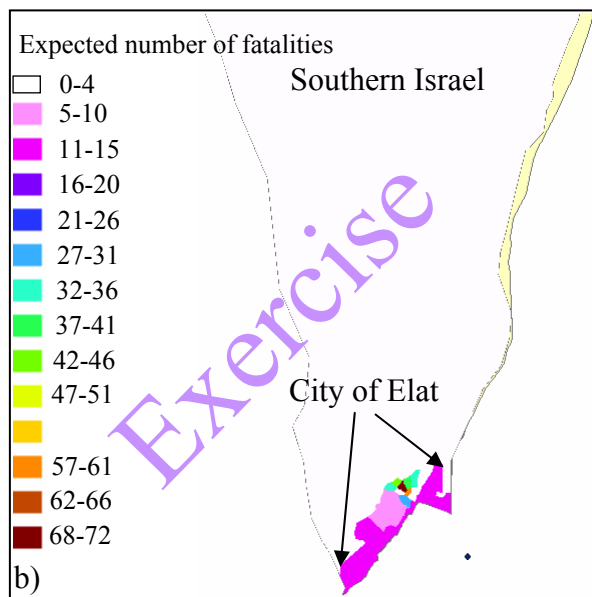
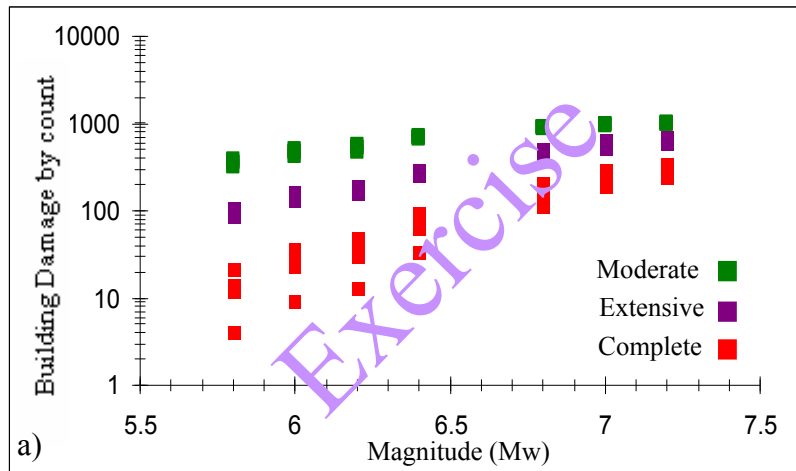
**Figure 2:** Demographic map of the study area. The Israeli population is divided into eight districts in the HAZUS platform.



**Figure 3:** The Israeli building stock as input in the HAZUS platform, divided into census tracts. The upper line on the right map shows the Haifa zone and lower right map, the Beth She'an zone. The yellow colour in the Israeli region marks a small area that is not divided to census tracts (no inhabitants), whereas for that in the Palestinian authority there is no data. Note that the area of the census tracts in southern Israel is larger since this area is less inhabited. The small census tracts in Judea and Samaria districts represent the Israeli citizens. Unfortunately, no data was available for the Palestinian people.



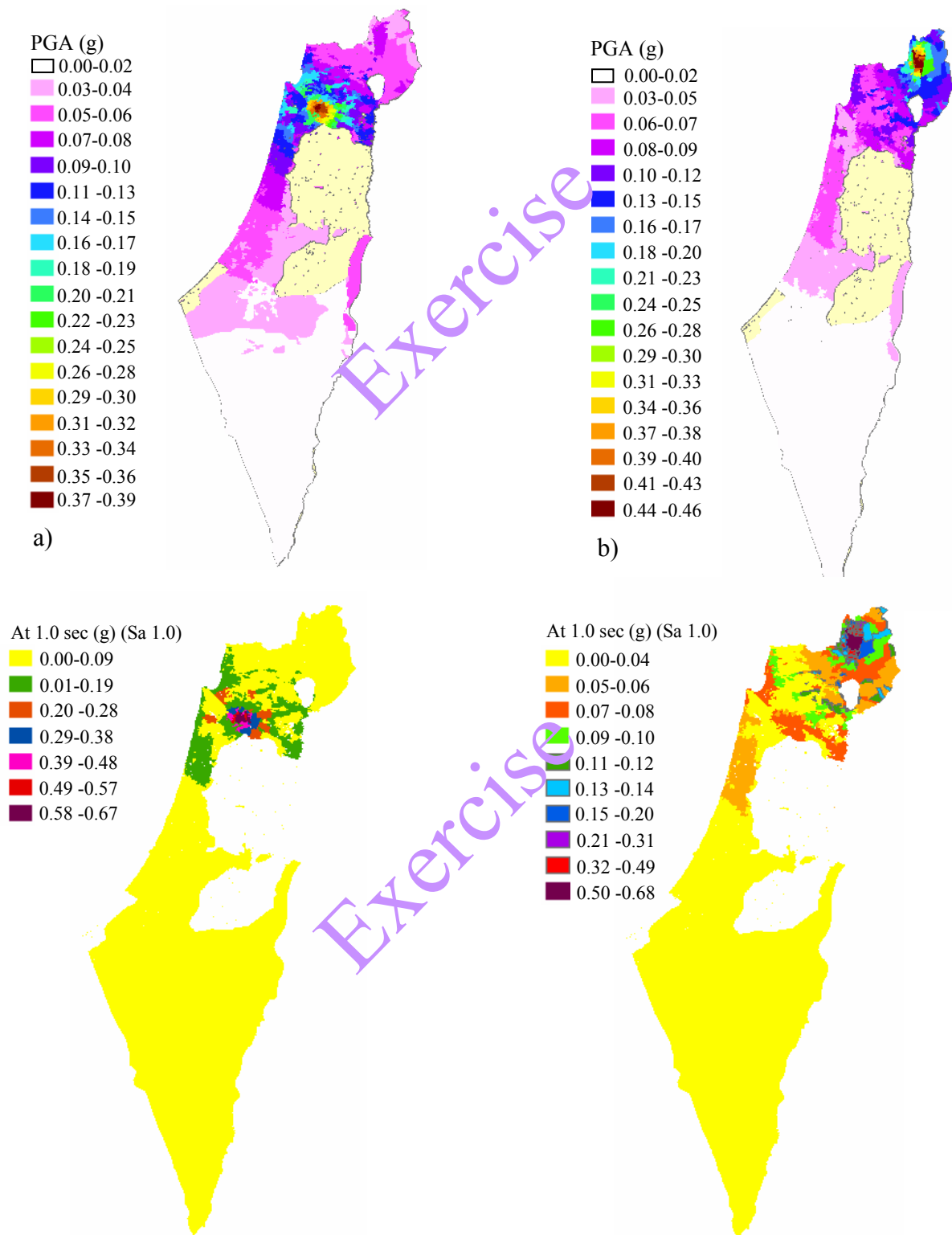
**Figure 4:** Results of seven simulation runs of the "Nuweiba scenario" (7.2 Mw) based on Table 1, showing the number of buildings expected to be damaged at three different severity levels. The legend represents the Israeli building types and the seismic codes used for the simulation (see Table 1). The stars represent the actual number of buildings that were damaged by the Nuweiba earthquake.



**Figure 5:** Results of the "Elat scenario": a) the number of the buildings expected to be damaged by a range of earthquake magnitudes. b) the number of people per census tract that may be fatally injured within the Elat city area in an Mw =6.5 scenario.

The building types and their distribution are defined by URML (50%) and C1L (50%) (see Table 1). In this example the assumption is that 250 per 1000 people that are under the collapsed buildings will supposedly be killed.

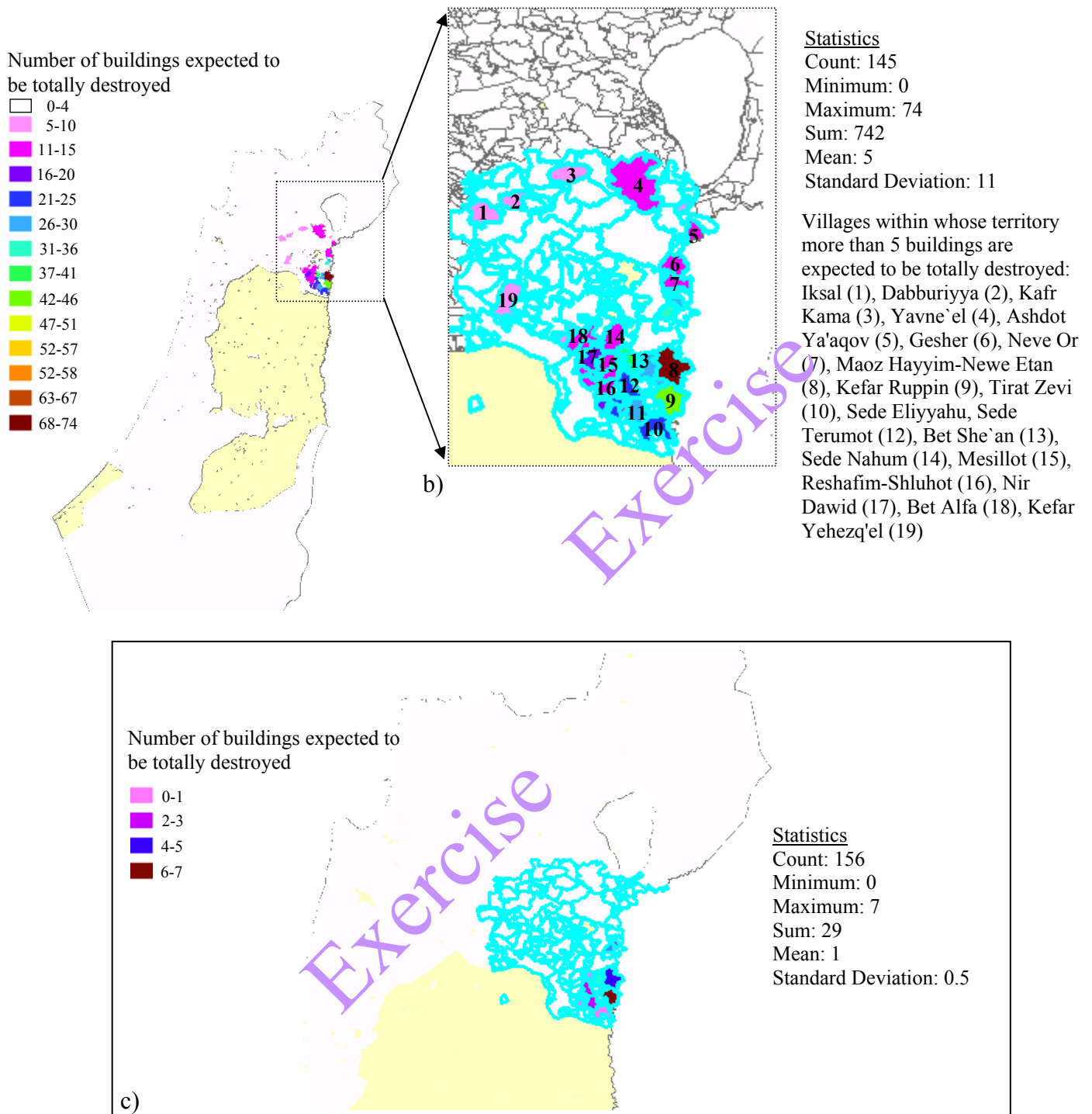




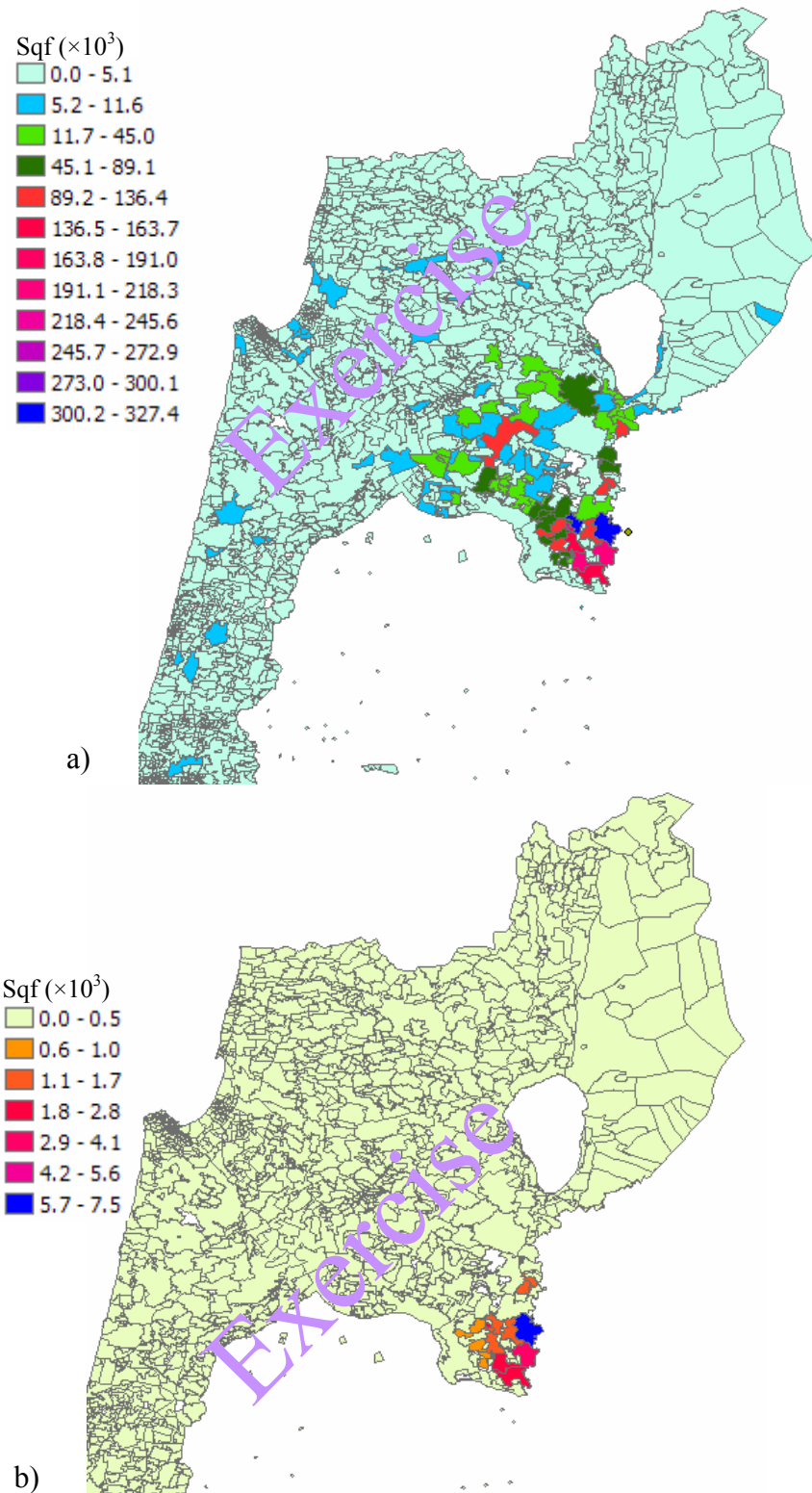
**Figure 6:** PGA and spectral acceleration estimates in different earthquake scenarios in northern Israel. The PGA is calculated based on the equation proposed by Boore et al. (1997):

$(\ln Y = b_1 + b_2(M - 6) + b_3(M - 6)^2 + b_5 \ln r + b_V \ln(V_S/V_A))$ , where Y is the peak ground acceleration, M is moment magnitude,  $V_S$  is the shear wave velocity for the station and  $b_1$ ,  $b_2$ ,  $b_3$ ,  $b_5$ ,  $b_V$ , and  $V_A$  are the parameters to be determined (for more details see the HAZUS manual).

a) PGA estimates for the synthetic "Emeq Yizre'el scenario" (6.5 Mw, 13 km depth). b) PGA estimates for the synthetic "Hula scenario" (7.0 Mw, 13 km depth). c) Acceleration estimates at 1.0 second for the synthetic "Emeq Yizre'el scenario" (6.5 Mw, 13 km depth). d) Acceleration estimates at 1.0 second for the synthetic "Hula scenario" (7.0 Mw, 13 km depth).

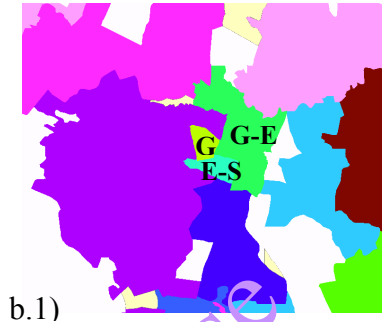
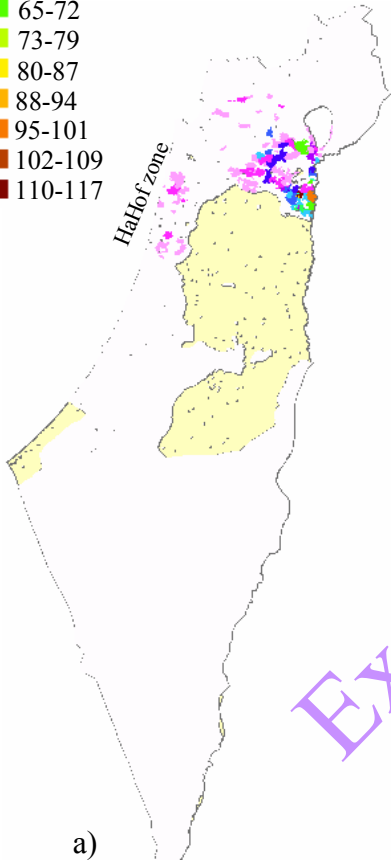
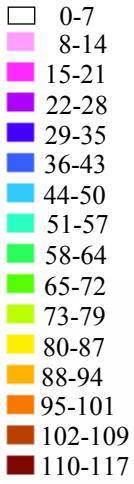


**Figure7:** Results of the "Bet She'an scenario" (6.5 Mw): a) the number of the buildings that are expected to be totally destroyed in the Israeli area. It is assumed here that all the building types are defined by the URML code, which is the worst anti-seismic quality code and not a realistic scenario. b) An enlarged map of the surrounding area close to the synthetic epicenter. The blue lines mark the selected polygons that are used for the statistical analyses. This shows that the HAZUS platform, at present, can give different damage statistics for different zones immediately after the earthquake event. This ability could improve the preparedness and the response of the emergency authorities in giving adequate treatment within areas in which most of the buildings are expected to be destroyed. On the right side there is an example of a statistics list calculated for the selected census tracts. c) Shown is the number of the buildings that are expected to be totally destroyed within Israel. In this simulation the assumption is that all the building types in Israel are defined by the C1H code, which is not a realistic scenario. The blue lines mark the selected polygons that are used for the statistical analyses.



**Figure 8:** Results of the "Bet She'an scenario" (6.5 Mw): a) calculated area of the building expected to be completely damaged, by square feet. In this case, all the building types are defined by the URML code, which is not a realistic scenario. c) Shows the building damage (complete) by square feet within Israel's area. In this simulation the assumption is that all the building types in Israel are defined by the C1H code, which is not a realistic scenario.

Number of buildings expected to be damaged at severity 3



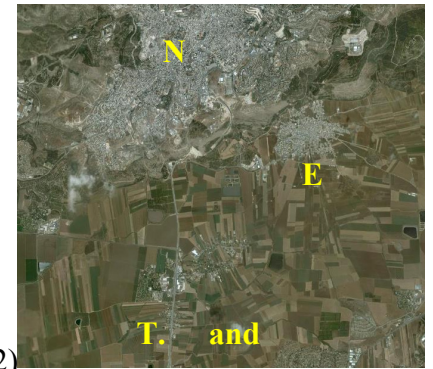
b.2)



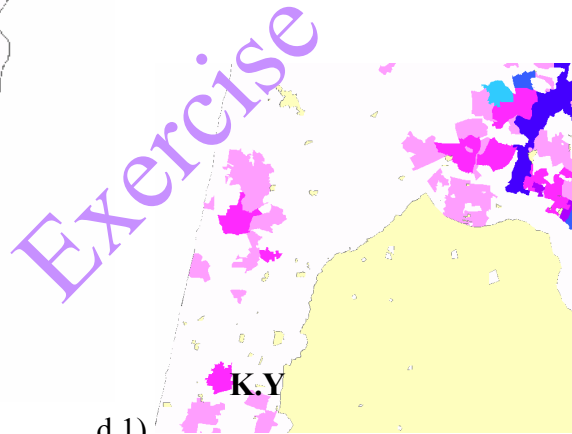
c.1)



c.2)



d.1)

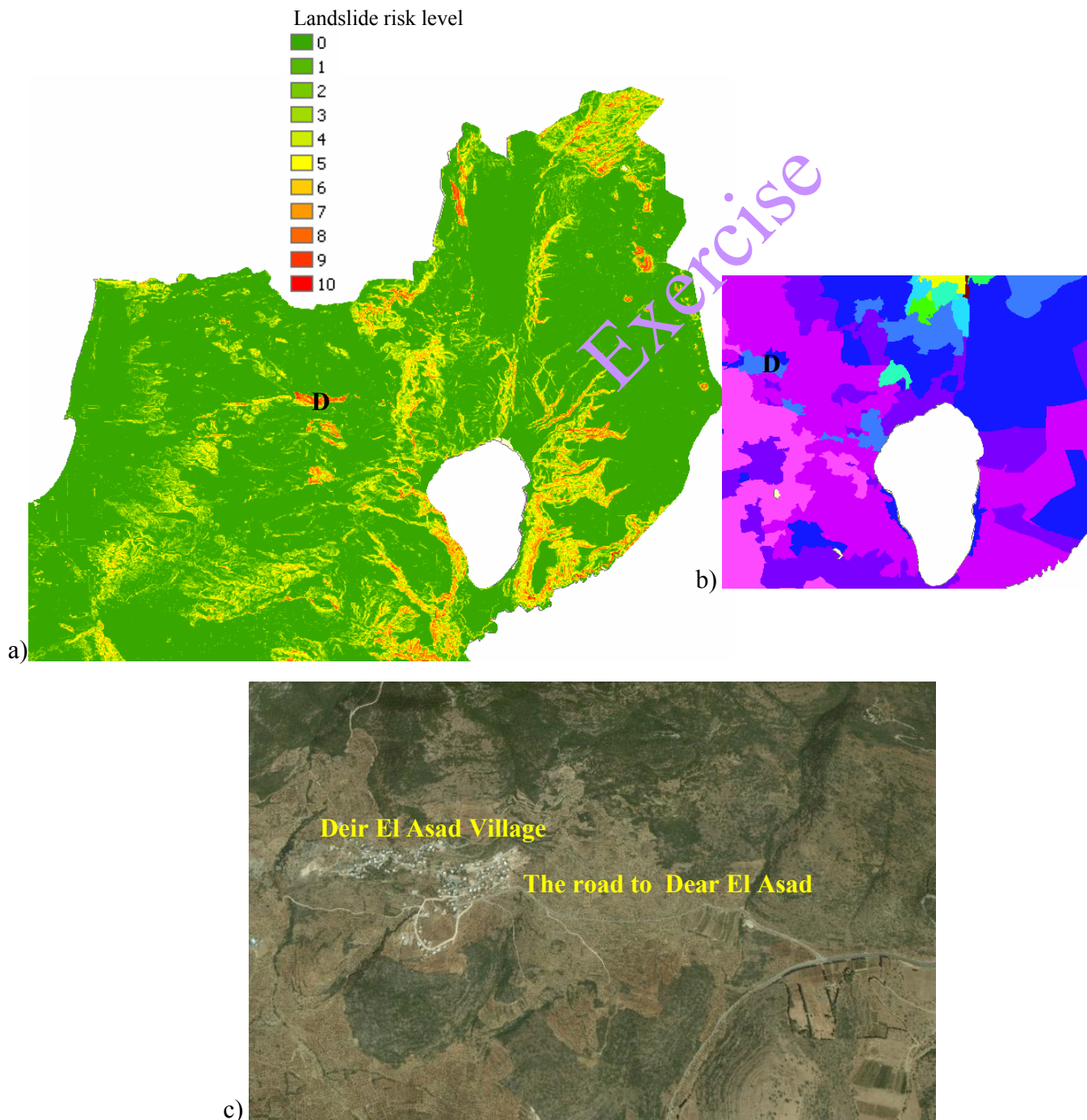


d.2)

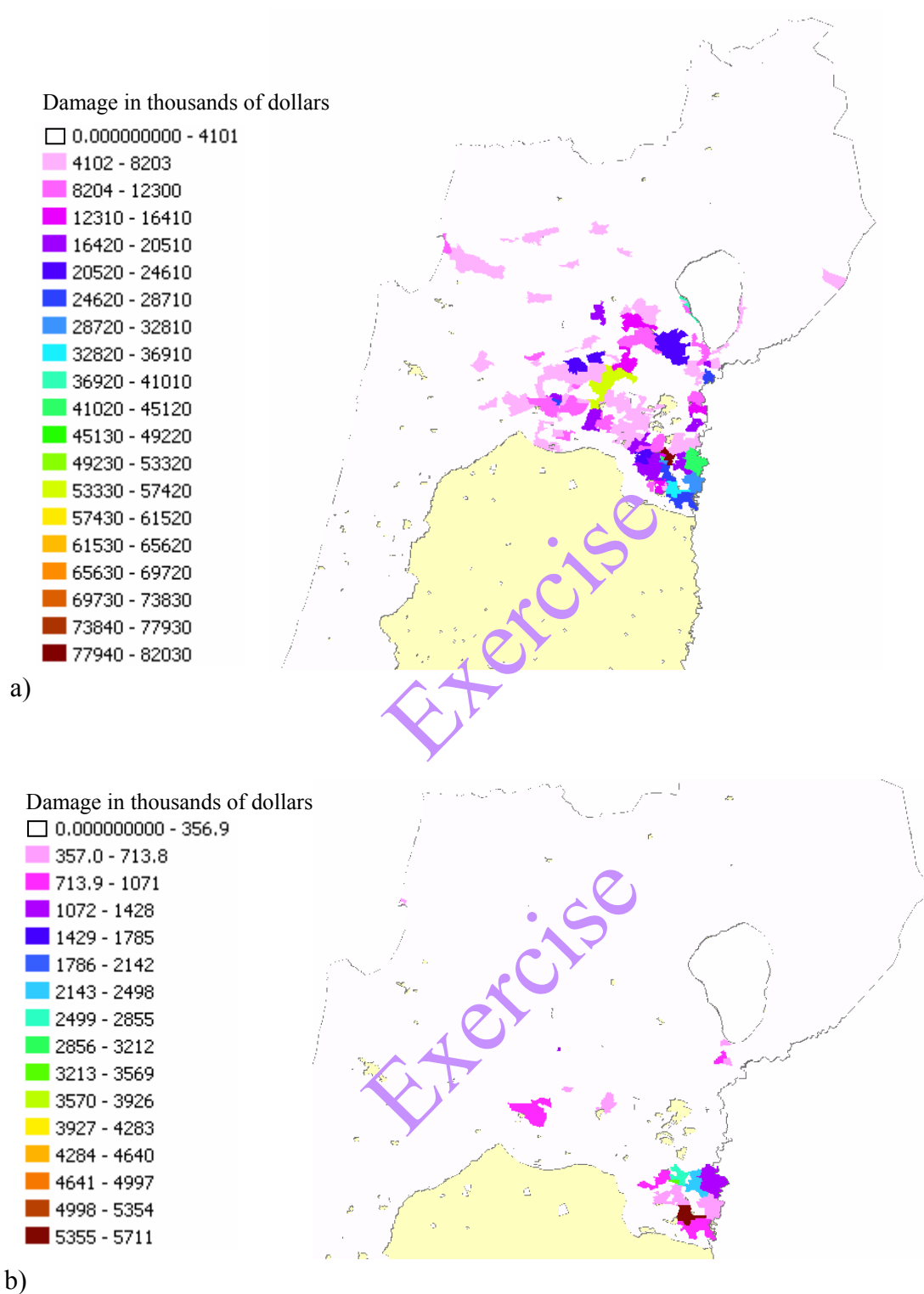


**Figure 9:** Results of the "Bet She'an scenario" (6.5 MW, 13 km depth). The figure shows the concentration of the number of buildings in different zones that are expected to be intensively damaged (severity 3): a) shows the simulation results using the URML code. Note that similar numbers of buildings are both expected to be close and far away from the synthetic epicenter. b.1)-d.1) shows an enlarged map of Figure a, of specific selected zones. b.2)-d.2) are the air photos of specific villages or neighbourhoods that are identified by transferring the USA coordinate system and census tracts onto the local Israeli coordinate system. In b.1)-b.2) the neighbourhood squares of the Bet She'an city are: Gordon, Eliyahu and Haluzim marked by G, E and H, respectively. Notably, the number of buildings that are expected to be damaged within the Gordon, Haluzim and Eliyahu squares are about 4.5%, 8.7% and 8.2% of the total number of buildings, respectively. In c.1)-c.2) the city of Nazareth, the Iksal and the Tel-Adashim/Mizra villages are marked by N, I and T-M, respectively. Differences in the numbers of building damaged between census tracts are related to differences in the ground acceleration magnitudes

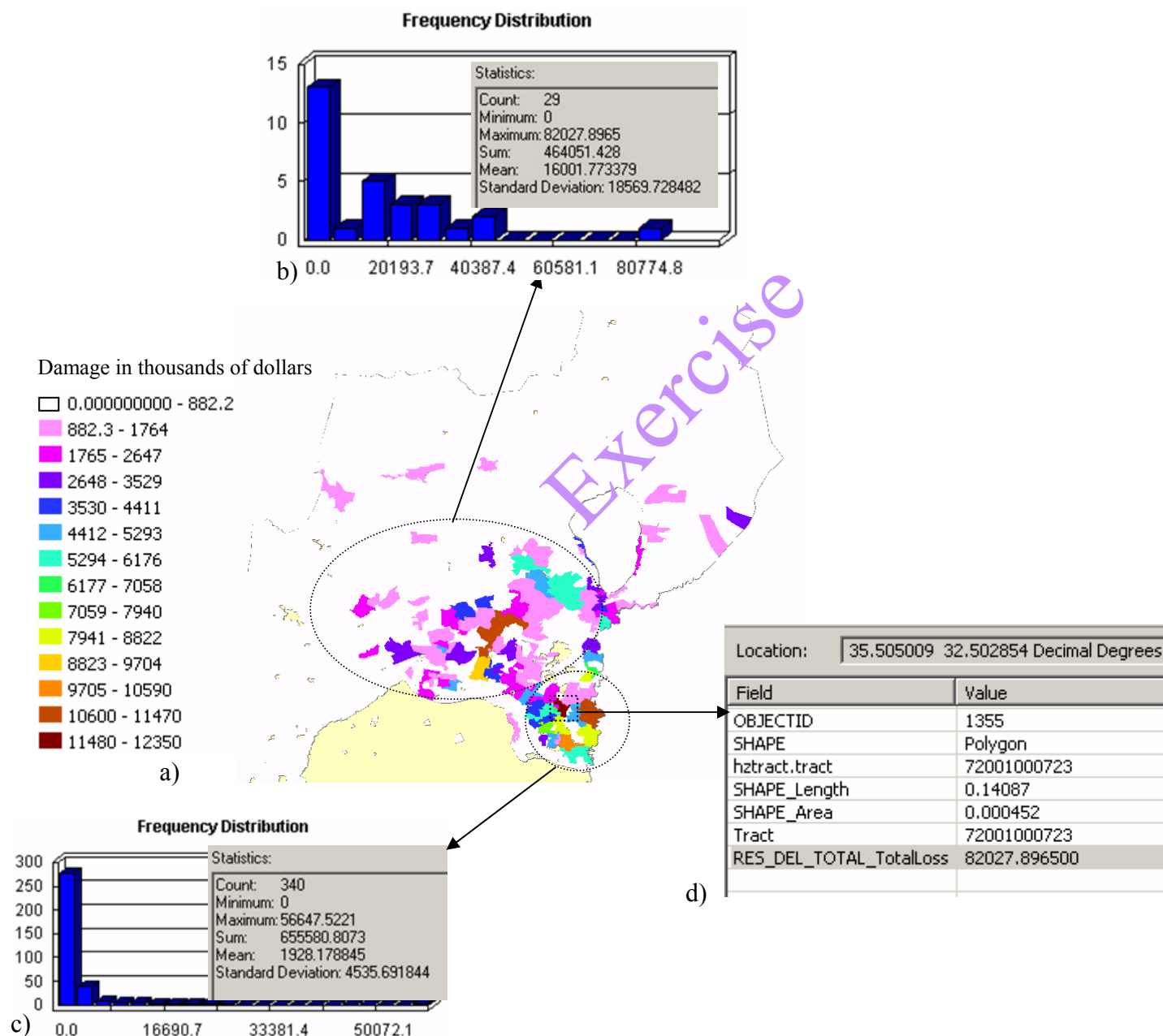




**Figure 10:** Results of the "Hula scenario" (6.5 MW, 13 km depth) a) presents the HAZUS ability to identify specific sensitive areas to landslides during an earthquake event. a) shows a landslide-susceptibility map (Katz et al., 2008) of the northern area in Israel. According to the critical acceleration levels around the zone that is marked by the broken ellipses, only 0.05 g is needed to generate a landslide. b) PGA estimation map shows that during the Hula earthquake scenario about 0.1 g is expected be in the zone marked with broken ellipses. Geographically, the marked zone of Figure b) is part of the zone that is marked in Figure a). c) shows an air photo of the Deir El Asad village zone within the marked zones that are identified in the two figures above. This analysis suggests that during the "Hula scenario" the road to Deir El Asad almost certainly will be blocked by rockfalls.



**Figure11:** An example of a direct economic loss in the "Bet She'an scenario" presented by different types of calculation: a) shows the total concentration (including building content) of direct economic loss in Israel given in thousands of US dollars; and b) shows the concentration of direct economic loss for educational buildings in Israel, given in thousands of US dollars.



**Figure 12:** Shows a direct economic loss without time restoration and loss of building content simulated in the "Bet She'an scenario": a) shows the concentration of direct economic loss in Israel given in thousands of US dollars; b) shows a plot of statistical analyses of the economic loss taken from the HAZUS simulation. The analysis is made for 29 selected census tracts that are relatively far from the synthetic epicenter. The selected census tracts are marked by large broken ellipses. In this example the total loss is about 465 million US dollars; c) shows the statistical analyses of the economic loss for 340 selected census tracts that are relatively close to the synthetic epicenter. The selected census tracts are marked by the broken circle. In this example the total loss is about 656 million US dollars; d) shows an identified plot of one selected census tract (Object I.D. number 1355) within the city of Bet She'an. The total economic loss for the selected census tract is about 82 million US dollars.

**Table 1:** The main Israeli buildings types. (For more details see Table 3.1 in the technical manual of HAZUS)

<b>Label</b>	<b>Israeli building types</b>	<b>HAZUS code</b>	<b>Building type quality</b>
C2 (L, M, H)	Concrete Shear Walls	19,20,21	I/best quality
C1 (L, M, H)	Concrete Moment Frame	16,17,18	II
C3 (L, M, H)	Concrete Frame with Unreinforced Masonry Infill Walls	22,23,24	III
C1 (L, M, H)- C3 (L, M, H)	Concrete Moment Frame- Concrete Moment Frame with Unreinforced Masonry	16,17,18 22,23,24	IV
PC1	Precast Concrete Tilt-Up Walls	25	V
C2 (L, M, H)- PC2 (L, M, H)	Precast Concrete Frames with Concrete Shear Walls	26,27,28 19,20,21	VI
URM (L, M)	Unreinforced Masonry Bearing Walls	34,35	VII/worse quality



**Table 2:** Earthquake scenarios.

<b>Earthquake scenarios (Synthetic)</b>	<b>Location (Israel DTM new grid )</b>	<b>Magnitude (MW)</b>	<b>Attenuation function</b>	<b>Depth (km)</b>
"Nuweiba scenario"	173899(E) 298322(N)	7.2	Boore, Joyner and Fumal, 1997	13
"Elat scenario"	198659(E) 380716(N)	6.2-7.2	Boore, Joyner and Fumal, 1997	13
"Southern Dead Sea scenario"	240464(E) 570953(N)	6.5	Boore, Joyner and Fumal, 1997	13
"Jericho scenario"	240464(E) 570953(N)	6.5	Boore, Joyner and Fumal, 1997	13
"Beth She'an scenario"	255690(E) 710159(N)	6.5	Boore, Joyner and Fumal, 1997	13
"Emeq Yizre'el scenario"	218076(N) 728012(E)	6.5	Boore, Joyner and Fumal, 1997	13
"Hula scenario"	257304(E) 779481(N)	6.5	Boore, Joyner and Fumal, 1997	13



בכדי לשפר בעתיד את יכולת התוכנה לאמוד בצורה מהימנה יותר את הנזקים, יש לפתח עקומות שבירות מקומיות עבור המבנים בישראל, השלמת רשומות המידע הדמוגרפיות, קליטה של רשומות תשתיות שונות, עדכון של רשומת מבנים, פיתוח של אומדני נזק סביב קו העתק, הכנסת מפות הגברה תואמות, וכיול הפרמטרים השונים שקיימים בתוכנה לחישוב של נפגעים.

## תקציר

מדינת ישראל ממוקמת לאורך טרנספורם ים המלח, שהוא אחד ממערכות ההעתקים הפעילים ביותר במזרח הים התיכון. בהתבסס על מחקרים פלאוסיסמיים ותיעוד סיסמי מודרני ברור שרעידות אדמה חזקות ( $M_w$  6-7) לאורך טרנספורם ים המלח הן בלתי נמנעות ועלולות להתרחש בכל עת. לפיכך קיים צורך דחוף שמקבלי ההחלטה ורשויות החרום בישראל יערכו לקראת רעידת אדמה חזקה. פיתוח הדמיות נזקים הנו אחד מהכלים החשובים ביותר לתכנון והערכות טובה ומוקדמת, כמו גם למזעור סיכונים. אך עד כה, תרחישי נזק לרעידות אדמה בישראל פותחו בהתבסס רק על סולם היזק סיסמי (Seismic Intensity Scale).

מטרת העבודה הנוכחית היא לאמץ באופן ראשוני את התוכנה האמריקאית המתקדמת HAZUS, שמיועדת ליצור הדמיות שונות של תרחישי נזק המתקבלים בעת רעידות אדמה. הדמיות הנזקים בתוכנה זו נעשות על ידי חישוב ברשת פוליגונים ארצית של תנודות הקרקע וחישוב של נזק למבנים על פי ידע הנדסי, עבור רשומות של המבנים הארציים. בכדי לאמוד את הנזק למבנים ואת הפגיעה בנפש הוכנו והותאמו למבנה של התוכנה החדשה רשומות מידע דמוגרפיים, רשומות מידע של מבנים שונים ומפורטים ומפות גיאוטכניות.

במסגרת המבחן של התאמת התוכנה לישראל ויכולתה החישובית, הורצו שבע הדמיות של רעידות אדמה סינתטיות שונות, בעוצמות שונות ( $M_w=6-7$ ) ובמקומות שונים לאורך טרנספורם של ים המלח ועמק יזרעאל. ההדמיות התבססו על התפלגויות של איכות מבנים משתנה במרחב, ועל טווח רחב של קודים סיסמיים עבור מבנים שונים.

תוצאות ההרצות מראות בברור שהנזק למבנים תלוי מאוד בטיב הבנייה וביחידות הגיאוטכניות. לדוגמא, במקרה של רעידת אדמה בעוצמה  $M_w=6.5$ , כאשר המוקד סמוך לעיר בית שאן, מאות מבנים צפויים להיהרס כאשר מניחים קוד סיסמי שמתאים למבנים העשויים מבלוקים. לעומת זאת, כאשר מניחים קוד סיסמי של מבנים העשויים מבטון, רק כמה עשרות מבנים עלולים לקרוס.

בהתאם למספר המבנים הצפוי להיהרס, גם מספר ההרוגים הצפוי הוא בין כמה בודדים ועד למאות הרוגים. מאחר והרשומות הדמוגרפיות חלקיות בלבד, הערכת תנודות הקרקע בקרבת ההעתק ובאזורי ההגברה ראשונית בלבד, ועדיין לא ידוע מה הוא אחוז הנפגעים האופייני בעת קריסת מבנה בישראל כתוצאה מרעידת אדמה (מקדמי אומדן הנפגעים), הרי ייתכן שהנזק למבנים ואובדן בנפש יכול להיות יותר גבוה.

תוצאות מבחן ההרצות הראשוניות בתוכנת התרחישים בישראל כמו גם הניסיון שהצטבר בעולם, מעידים באופן ברור שלפלטפורמה של תוכנת ה HAZUS יש את מירב היתרונות להיות כלי מודרני ושימושי להערכת נזקים צפויים (פגיעות בנפש, נזקים למבנים, תשתיות ורכוש) לקראת רעידת אדמה חזקה בישראל. יתר על כן, תוכנה זאת תוכל להוות בעתיד כלי שימושי רב תכליתי לצורך תרגול ומתן מענה של רשויות החרום בישראל. התוצאות הראשוניות שהתקבלו מהרצת התרחישים בתוכנת HAZUS כפי שמוצגות בעבודה הנוכחית, מלמדות שיישום התוכנה במלואה בישראל הינה משימה אפשרית ואף הכרחית.



משרד התשתיות הלאומיות  
המכון הגיאולוגי

## **הדמיית נזקים מרעידות אדמה בישראל בעזרת תוכנת HAZUS יישום ראשוני**

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