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EARTHQUAKE HAZARD ASSESSMENT STUDIES IN THE STATE OF KUWAIT

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ABSTRACT: This study addresses the first and most important step in measuring the level of seismic hazard in Kuwait. As a result of development, there has been a rise in urban growth leading to the establishment of massive structures and skyscrapers in Kuwait. Therefore, there is demand for seismic risk assessment and the creation of a single seismic code for the country. Consequently, the historical and instrumental data were compiled into seismic catalogs of Kuwait and the active Zagros Seismic Belt. The magnitudes have been unified, extraneous earthquakes removed, and the catalogs' entirety has been taken into account. A seismotectonic model for the Kuwait region has been built to minimize the epistemic uncertainties. The model functions by combining seismicity patterns and structural geological conditions. The probability of experiencing the largest predicted earthquake emerging from every seismic source was calculated together with the parameters set for recurrence. Furthermore, the creation of hazard maps required a suitable ground motion attenuation relation within a logic tree design. Considering recurrence intervals of 100, 475, 975, and 2475 years (corresponding to 39.3 percent, 10%, 5%, and 2%, accordingly, the likelihood of exceedance in 50 years), a probability-based technique is utilized in the study to construct hazard maps at the following 0, 0.1, 0.2, 0.5, 1, 2, 3 and 4 seconds. The maps of scaling hazard areas were created using a 0.2 ° x 0.2 ° spacing grid throughout Kuwait. The five regions of Kuwait (Kuwait City, Salmiya Area, Sabriya Area, Managish Area, and Um Gudair Area) have all implemented a consistent spectrum of hazards. The findings of this study plus the vulnerability index serve the essential features required to calculate Kuwait's seismic risk.

Keywords: Attenuation Relations, Seismic Hazard Spectral, Maximum Magnitude, Recurrence, Managish.

1. INTRODUCTION

In this study, the probabilistic seismic hazard approach [1], [2] is used to epistemic uncertainty treatment to assess seismic hazard considering the local seismicity of Kuwait and regional seismicity from its surroundings. Estimates the probability that the ground motion may or may not be exceeded at a certain level which is very important in evaluating the chance of failure and designing building codes [3], [4]. The first step in the hazard analysis is to compile an earthquake catalog [5], [6]. It is followed by building a seismotectonic source model and estimating the recurrence parameters and maximum predicted magnitude in each seismic source specified in this model [7]. Finally, an appropriate ground motion attenuation relationship is applied to estimate the seismic hazard [8], [9].

Throughout Kuwait, seismic hazard maps were generated using a 0.2° grid to produce 5% damped spectral acceleration values on the bedrock for the Peak ground acceleration (PGA) and spectral periods of 0, 0.1, 0.2, 0.5, 1, 2, 3 and 4 s at return periods of 100, 475, 975 and 2475 years, which are equivalent to (60%, 90%, 95%, and 98%, respectively, probability of non-exceedance of ground motion in 50 years). Uniform hazard spectrum (UHS) was estimated at Kuwait City, Managish Area, Sabriya Area, Salmiya Area, and Um Gudair Area to determine the hazard at spectral periods ranging from 0 to 4 seconds. For the earthquake designer, these are the most important periods [10].

The State of Kuwait is located in the northeastern corner of the Arabian Peninsula between latitudes 28°30' and 30°N and longitudes 46°30' and 48°30'E. The State of Kuwait represents the northwestern tip of the Arabian Gulf, bordered to the east, to the south and southwest by the Kingdom of Saudi Arabia, and the west and north by the Republic of Iraq. The area of the State of Kuwait is about 17,818 km2. Seismic activity in the State of Kuwait is low to moderate [11], [12]. It has been affected by several local earthquakes such as the January 16, 1977 earthquake (Local magnitude (ML)= 4.5) which occurred at 28.8°N, 48.1°E and the June 2, 1993 earthquake (ML = 4.8) which occurred at 29.0°N and 47.6° [13], [14].

After the earthquake that occurred in 1993, the Kuwaiti government decided to establish a national seismic network and entrusted the construction and operation of this network to the Kuwait Institute for Scientific Research (KISR) [15]. The neighboring countries of Kuwait in the past ten years have been subjected to hundreds of earthquakes, and this had an impact on Kuwait, felt by the residents of Kuwait on January 6, 2019, with a magnitude of 5.9 on the Richter scale. It was on the Iranian-Iraqi border. Kuwaitis felt a 7.5-magnitude earthquake on the Iraq-Iran border on November 12, 2017, as shown in (Fig.1).

2. RESEARCH SIGNIFICANCE

Due to Kuwait's proximity to the famous earthquake belt in Iran, the Zagros earthquake belt, and the local earthquakes that usually occur in Kuwait due to the occurrence of the oil extraction process [13]. It has become the need of the hour to address the issue of inconsiderate construction and negligence towards the seismic performance of buildings and structures to resist the effects of quakes. The aim of the current study is preventive policy must be devised keeping in view the aspects like i) the seismic assessment, ii) the compliance of builders to safe building construction codes, iii) enhancing public awareness about the earthquakes, and iv) introduction of a plan for proper planning related to land-use particularly in regions with high seismic hazard and higher risk of other natural calamities. This study may benefit decision-makers in Kuwait by identifying the location of the most dangerous seismic hazards in Kuwait.

3. STRUCTURE AND SEISMICITY

The tectonic collision which has formed the Zagros fold belt in Iran has had a significant impact on Kuwait. This connection is explained by the location of the fold belt in the northeastern region of the Arabian Peninsula, as shown in (Fig.2). Several researchers have investigated the area's structural and tectonic conditions [13,16,17,11,18,19,12]. It was found that the crustal reduction rate along the Zagros Thrust fold belt is around 10 mm annually in the southeast and 5 mm annually in the northwest [20,21]. The Zagros fold belt experiences all three, small, moderate, and major earthquakes that have magnitudes around 7.5. These earthquakes occur at varying depths (low, medium, and deep) along this belt (Fig.1). The active Pliocene band is 1500 kilometers long and has a width of 200-300 kilometers. In an NW-SE orientation, it stretches from eastern Turkey in the north to Oman in the south [22,23,24]. The uplift of mountains, principally induced by the collision zone and degradation in the region, caused the formation of a sedimentary layer of seven to ten km thickness.

According to [18], the highest primary horizontal stress field is oriented along NE-SW (Kuwait Arch) and abrupt curving that defines the Zagros belt in an NW-SE orientation dominates Kuwait's topography. The anticlines found in Quaternary depositions of the huge Burgan Oil Field located in southern Kuwait, that originated during the 4 Cretaceous eras, gave unequivocal proof of ongoing movement and elevation in the region.

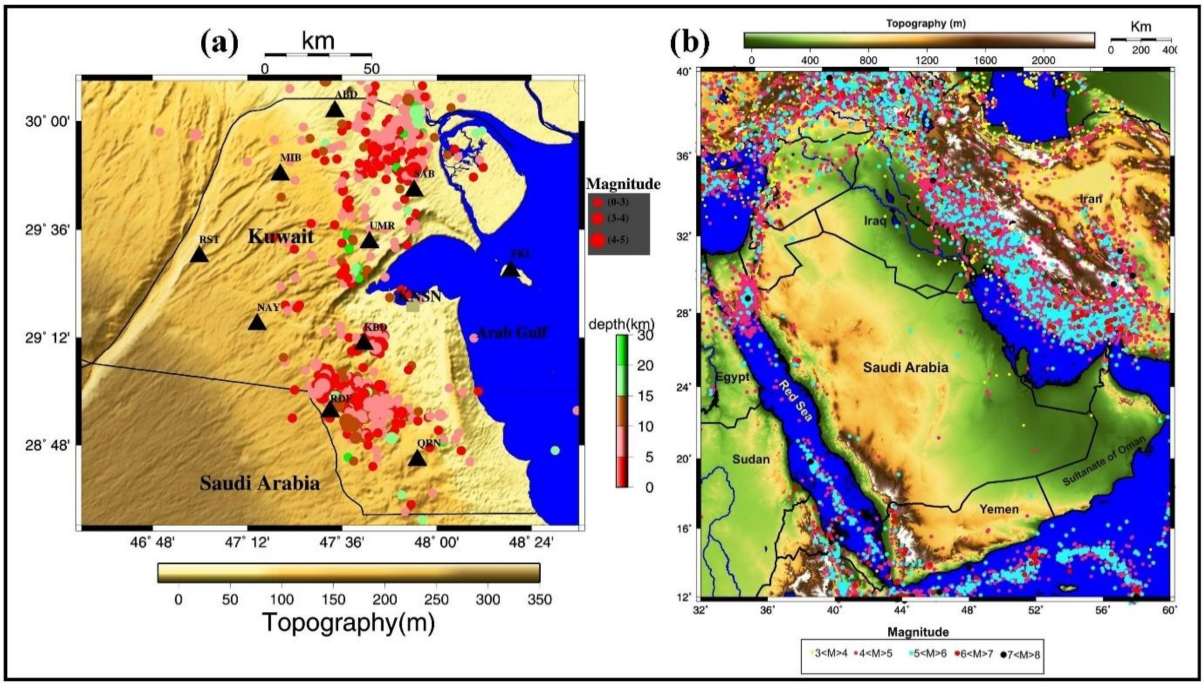

Fig.1. (a) KNSN Recording of Local Seismic Activity in the State of Kuwait from 1997 to 2020, (b) Record of regional seismic activity in the Arabian Peninsula and the neighboring areas of Kuwait from 1997 to 2020 (after A. K. Abd el-aal 2021[16]).

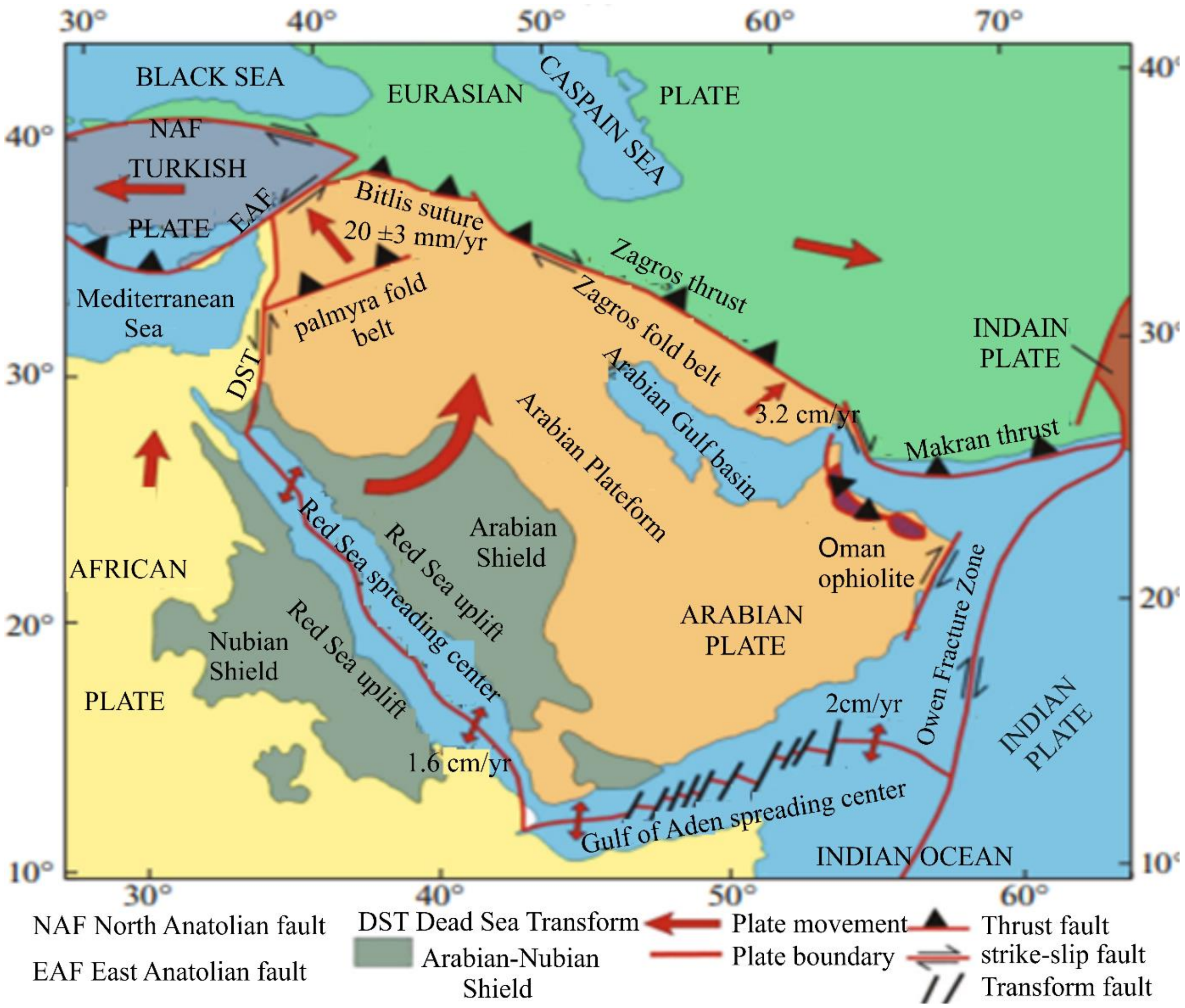

Fig.2. The boundaries of the Arabian Plate relative to its neighboring plates (modified after Johnson, 1998[25]).

The extraction of oil, according to [13,12], is the triggering factor of earthquakes, especially for earthquakes that occur near an oil field. Figure3 depicts the city structure of Kuwait, which includes structural arches, anticlines, synclines, regional gradients, troughs, stylolites, fractures, and faults [19]. Figure 1 depicts the earthquake activity measured in Kuwait, Zagros, and the surrounding areas. Although studies show that Kuwait has a low rate of seismic activity, this conclusion may be incorrect due to the absence of documentation of any such seismic danger before the nineteenth century [13,16,17,26,12]. With the turn of the twentieth century, there was an increase in recorded cases. In the years 1931 (5th July), 1973 (14th March), 1976 (2nd January), 1976 (26th September), 1976 (27th September), 1977 (16th January), and 1993, earthquakes in Kuwait were instrumentally documented (1st July). The magnitudes of these earthquakes ranged from 4.7 to 4.6, 4.1 to 3.2, 3.8, 4.5, and 4.8, respectively, with the 1993 earthquake causing substantial property and other devastation in the city [13,26,12]. The emergence of the KNSN, which not only allowed semiologists to record even the smallest earthquakes but also let them precisely identify the seismic sources, considerably aided the process of recording earthquake data in Kuwait. Seismic activity was detected in Kuwait's southern and northeastern sectors from two sources: Managish-Um Gudair and Raudhatain-Sabriya, respectively.

4. METHODOLOGY

Kuwait's seismic hazard was investigated using PSHA, or the probabilistic seismic hazard approach. PSHA was introduced by [27] and modified by [28,29]. The equation below calculates the likelihood of an increase in ground motion level over a certain time frame.

$$P_t(z) = \sum_{j=1}^{k} \int_{m=M_{min}}^{m=M_{max}} P_t(\mathrm{m}) \int_{r=R_0}^{R_{max}} P(r)\ (P(A \geq Z)m, r)\ dmdr \quad (1)$$

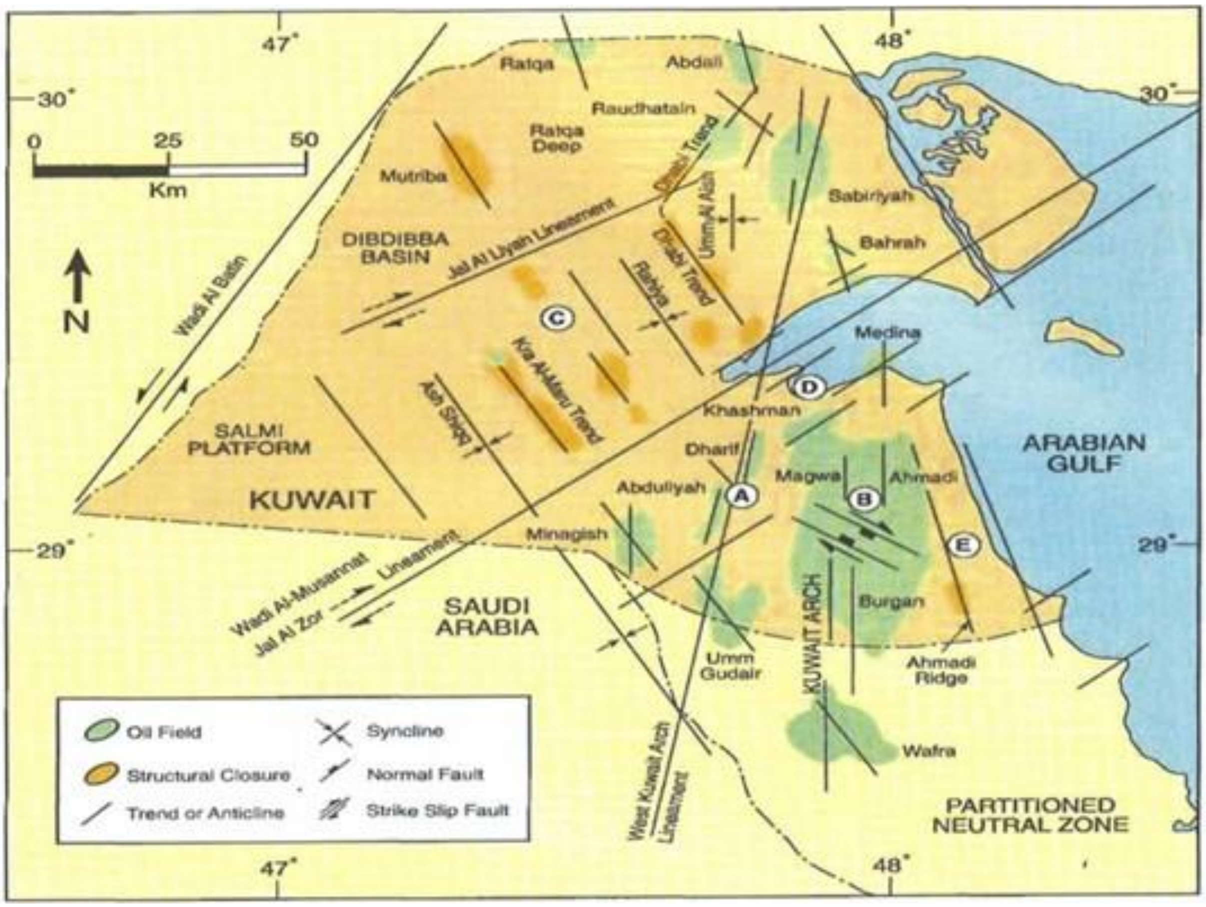

Fig.3. Structure map of Kuwait (after Carman 1996 [18]).

In the equation shown above, Pt(m) represents the probability of an earthquake incident occurring at a magnitude m over a seismic source j in a span of t years. Further, P(r) represents the probability of an earthquake incident occurring at a distance r from a specific region, while P $(A \geq Z)$ is the possibility that underground motion A will surpass underground motion level Z on a particular area. For this study, the Poisson model was employed to calculate the rate of earthquake magnitude exceedance for every seismic source. Firstly, after assembling the earthquake catalog, the first stage when evaluating a hazard is to create a seismotectonic source model to characterize the seismicity of each source. This is done using all data at hand on the geology, structure, tectonics, and seismicity in the research area. The seismicity recurrence parameters are then calculated to estimate the chance of an earthquake of a given magnitude occurring in every seismic source over a given timeframe. In addition, the maximum earthquake magnitude (Mmax), which indicates the maximum amount of rock displacement that is predicted to occur along the fault plane, for all seismic sources is computed to assess the seismic risk at a certain location where essential structures are designed. To put it another way, anytime a large earthquake occurs, the quantity of rock displacement increases, and vice versa. Furthermore, ground motion relation is employed when referring to earthquake magnitude and distance from the location. This is done to mitigate earthquakes created in each seismic source. Using different seismotectonic source models and ground motion interactions within a logic tree framework further lowered epistemic uncertainty. The protocol chart utilized in this investigation is shown in Fig.4.

4.1. Input Of PSHA

When evaluating any type of seismic hazard, the initial step is to create a comprehensive, consistent, and accurate database for the earthquake. This database must incorporate all accessible instrumental data. Information on the seismic hazard in Kuwait was gathered from various sources, including a compilation of local events that occurred in Kuwait from 1997 to 2019 obtained through the Kuwait National Seismic Network [15].

Moreover, details on instrumental earthquakes that occurred between 1907 and 2019 were gathered through multiple sources. Because the KNSN had recorded the data for the earthquakes using the local magnitude (Ml) scale, and it had to be translated to the moment magnitude scale, according to A. K. Abd el-aal [30] a linear regression relationship was also established Eq. (2). There was only a limited amount of moment earthquake data available for the Kuwait study. With confidence ranges estimated at 95%, this small amount of data was used to determine the link between the local and moment magnitude scale in Kuwait as follows.

$$\mathrm{Mw} = 0.87(\mathrm{Ml})(\pm 0.07) + 0.2392(\pm 0.2) \quad (2)$$

For the above-mentioned formula, the moment magnitude is denoted by Mw and the local magnitude by Ml. The European Mediterranean Seismological Center (EMSC) [31] archives were utilized to collect regional and teleseismic data from 2008 to 2019, while [32] database was used to extract additional regional data (1907 to 2010) and historical seismic data (for the years 628 to 1898). All additional data were combined into a single catalog after every event was corrected according to the Mw scale and redundant events were eliminated. The maximum number of earthquakes recorded in the catalog is 4957. The Mw scale was chosen because it is a very dependable magnitude scale that takes into consideration all essential factors such as the rupture zone on the fault plane, the extent of displacement across the fault plane, and the magnitude of the rock's strength. The elimination of dependent earthquakes like the fore- and aftershocks were carried out using the catalog declustering approach proposed by [33] which gives the catalog the appearance of a Poisson dataset [34]. Figure 1 depicts Kuwait and its environs' historical and instrumental seismicity over the years 628 to 1898 and 1907 to 2019. Medium and large earthquakes showing a ≥ 4.0 magnitude that occurred on the outskirts of Kuwait were utilized in the hazard study, with tiny earthquakes (Mw ≥ 2.5) being mostly used within Kuwait.

4.2. Seismic Source

Any location, (fault) line, volume sources, point, or dipping planes from where earthquakes may originate are considered seismic sources [35] which are the potential sources of earthquakes. Each source has its stress regime and seismicity, with each region of that source having the same chance of acting as the epicenter of a forthcoming earthquake. When it comes to earthquake study and prediction, a seismotectonic model is a must-have tool. It establishes the geographical borders of a seismic source capable of causing earthquakes. The seismotectonic model utilized in this study, which included 27 seismic sources, identified seismic source boundaries based on the geographic distribution of earthquake epicenters, structure and tectonic settings, seismic activity, and previous focal mechanism studies. The epistemic uncertainties in this study are depicted in (Fig.5). Furthermore, the characterization of floating earthquakes beyond the identified seismic sources occurs as a result of establishing a background seismic source in the seismotectonic model. To accommodate for epistemic errors, a logic tree structure was integrated with the model.

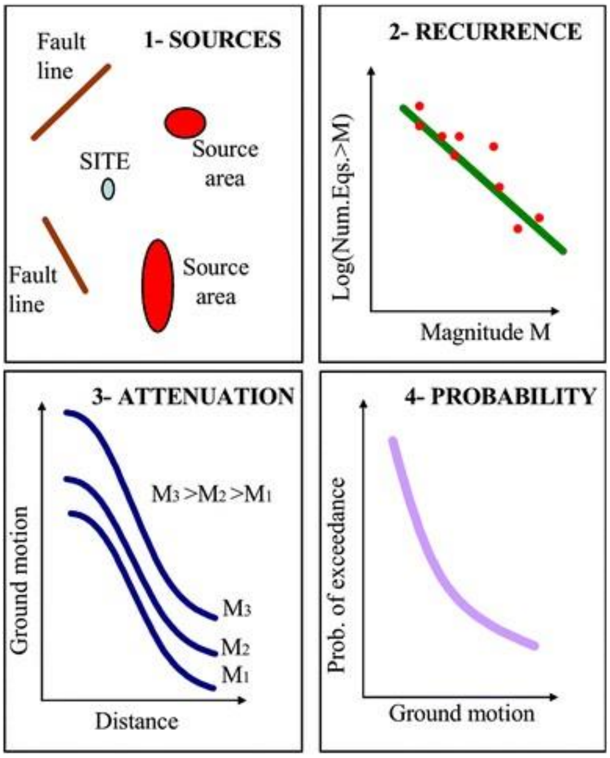

Fig.4. Steps of probabilistic seismic hazard analysis for a given site: (1) definition of earthquake sources, (2) earthquake recurrence characteristics for each source, (3) attenuation of ground motions with magnitude and distance, and (4) ground motions for the specified probability of exceedance levels (calculated by summing probabilities over all the sources, magnitudes, and distances).

4.3. Maximum Magnitude

The timing and likelihood of an earthquake event at any interval over the seismic source can be determined by estimating seismic recurrence parameters, which include β, b-value, and λ. The parameters are calculated using the [36] maximum likelihood method. Parameter β has a key role in determining the tectonics of every seismic source, as shown by the equation (β = b ln10), whereby b is the b value of [37] equation. The b-value parameter describes the approximate ratio of major and minor magnitude earthquakes, with fluctuations in the b-value reflecting changes in stress regimes (a lower b-value corresponds to high stress in a particular region and vice versa). Finally, the parameter λ represents the annual rate of activity or the frequency of earthquakes that occur. Furthermore, while some sources utilize the Robson-Whitlock-Cooke [38,39,40] strategy to forecast the maximum earthquake or Mmax in a particular seismic source, others use the method proposed by [40] when working with insufficient data [41]. Lastly, in seismic sources with few occurrences, the projected Mmax was calculated by adding 0.5 magnitude units to the greatest observed magnitude (Mmax obs.). Table 1 shows the seismicity recurrence parameters and Mmax for the seismotectonic source model as well as the standard deviations (STD) values.

4.4. Ground Motion Attenuation Relations

The magnitude of an earthquake, the distance determined between the source and the impacted site, and the acceleration are all connected via the probabilistic relation. This link is evaluated using attenuation models, which must be meticulously selected to diminish the seismic source of each earthquake. Because there was insufficient data on the ground motion for the earthquake in Kuwait, it was necessary to use previously known attenuation relations to estimate the ground motion of the earthquake starting at its epicenter and reaching the particular location. [42] and [43] attenuation models were employed in this research. The former was used to model the ground motion of seismic sources in Kuwait, while the latter was used to simulate the ground motion of outlying areas of Kuwait for a model of the seismotectonic source. In addition, the Mw scale is used in these attenuation relations to estimate ground motion on both the sites for large rocks and PGA and spectral accelerations for different periods.

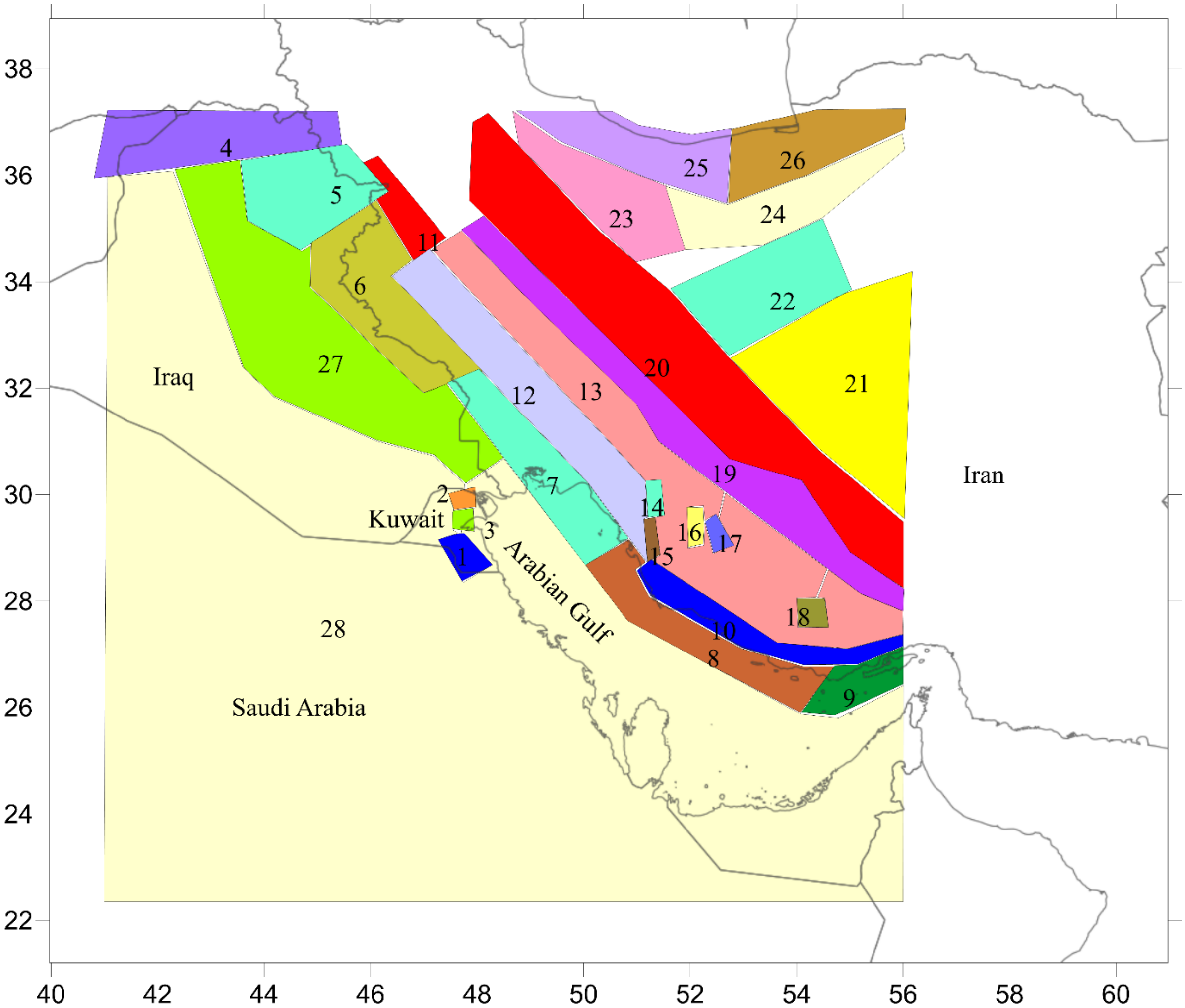

Fig.5. Seismotectonic source mode (coordinate taken after A. K. Abd el-aal [30]).

5. RESULT

To evaluate earthquakes in Kuwait, hazard maps were generated to produce 5 percent damped spectral acceleration readings for PGA with spectral intervals of 0.1, 0.2, 0.5, 1, 2, 3, and 4 seconds on bedrock for the seismotectonic source model. To prevent generalization of the results, the seismic hazard in Kuwait was assessed at 324 sites scattered over an area grid of 0.2° x 0.2° and its environs using the CRISIS (2007) software.

Table 1 Seismicity recurrence parameters and Mmax for the seismotectonic source model.

Seismic source	Threshold magnitude Mmin	Lower limit M_{max} obs.	Upper limit Max	The expected value of Beta β	Coefficient of variation of Beta STD	Lambda λ
1	2.5	4.8	5.3	2.08	0.19	2.39
2	2.5	4.5	5	2.09	0.26	1.637
3	2.33	4.2	4.7	2.29	0.42	0.901
4	4	6.5	7.5	1.6	0.2	0.941
5	4	6.3	7	1.5	0.19	0.957
6	4	7.3	7.6	1.75	0.08	0.707
7	4	6.4	7	1.83	0.25	0.377
8	4	5.9	6.6	1.65	0.21	1
9	4	6.7	7.4	1.32	0.12	1.18
10	4	6.4	7	1.73	0.1	1.754
11	4	5.1	5.8	2.16	0.41	0.388
12	4	6.7	7.2	1.7	0.07	0.901
13	4	6.9	7.3	1.59	0.05	1.395
14	4	5.9	6.5	1.62	0.25	0.723
15	4	5.8	6.5	1.93	0.25	1.51
16	3.99	5.8	6.5	2.05	0.28	1.183
17	4	6.1	6.5	1.54	0.27	0.8
18	4	6.4	7	1.19	0.2	0.242
19	4	6.5	7.1	1.64	0.14	0.884
20	4	6.5	7	1.53	0.19	0.417
21	4	6.8	7.4	1.79	0.22	1.389
22	3.6	4.4	5	2	0.45	0.217
23	4	7.1	7.7	0.91	0	0.025
24	3.8	7.1	7.7	1.36	0.29	1.901
25	3.9	4.7	5.4	2.24	0.44	1.626
26	3.7	5	5.5	1.87	0.33	3.803
27	4	7	7.3	1.4	0.22	0.08
28 BG	4	5.1	5.3	1.93	0.4	0.26

The calculated seismic dangers for return times 100, 475, 975, and 2475 years, correspond to 39.3%, 10%, 5%, and 2%, accordingly, of surpassing the ground motion in 50 years are illustrated in the (Fig. 6 to 9). This serves as the basic design life for any structure. Several seismic construction rules place a premium on these return durations, particularly the 475 years.

5.1. Seismic Hazards Maps

The seismic threat in Kuwait, according to the hazard maps, appears to be low to moderate. The growth observed at Sabriya and Um Gudair oil fields in northeastern and southwestern Kuwait, correspondingly, particularly at the PGA along with the brief spectral period of 0.1 seconds, implies seismicity in this region is caused by an inductive source. It is noteworthy that the seismic activity recorded at the Um Gudair oil field is greater compared to Sabriya. Additionally, seismic hazard findings for the seismotectonic source model revealed the greatest PGA readings in South Kuwait to be 47.3 gal at a return period of 475 years. The convergence of the Zagros fold belt in Iran raises the hazard level to the northeast of Kuwait state which indicates that particular region's seismotectonic setting. The maximum acceleration values appear on all seismic hazard maps operating with over a brief spectral period of 0.1 seconds exhibit maximum acceleration, while the low acceleration values are observable over a long spectral period of four seconds. As far as the source model is concerned, all maps that contain identical spectral accelerations at various return periods also showcase similar contour patterns of line. Hazard pattern, however, is significantly influenced by the architecture of the seismotectonic source model, particularly under PGA and 0.1 seconds spectral periods. Because the background source of seismicity reflects areas of minimal seismicity, it shows no bearing on the hazard estimations.

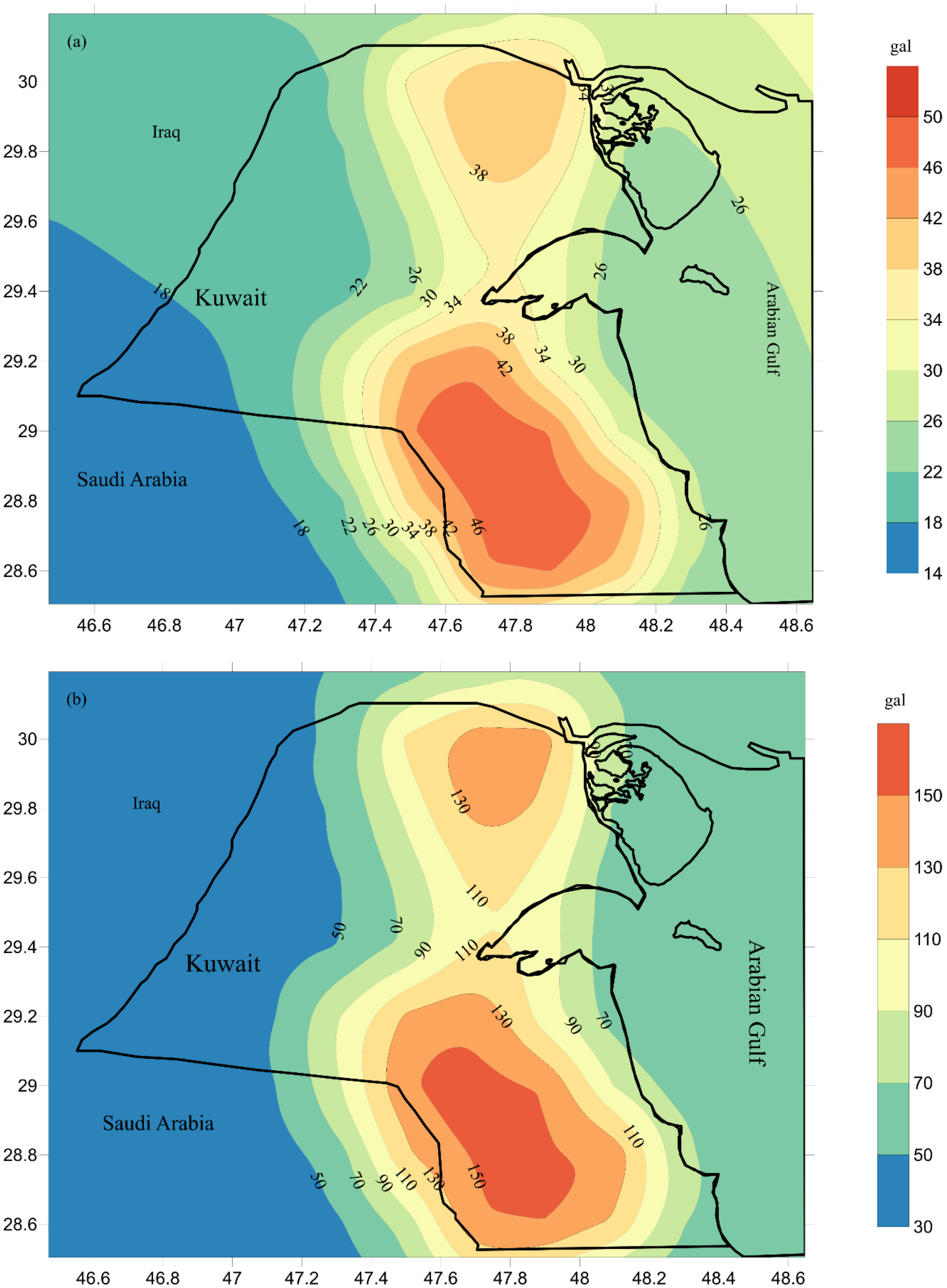

Fig.6. Seismic hazard maps of Kuwait for (a) PGA and (b) 0.1 s at a return period of 475 years on the rock.

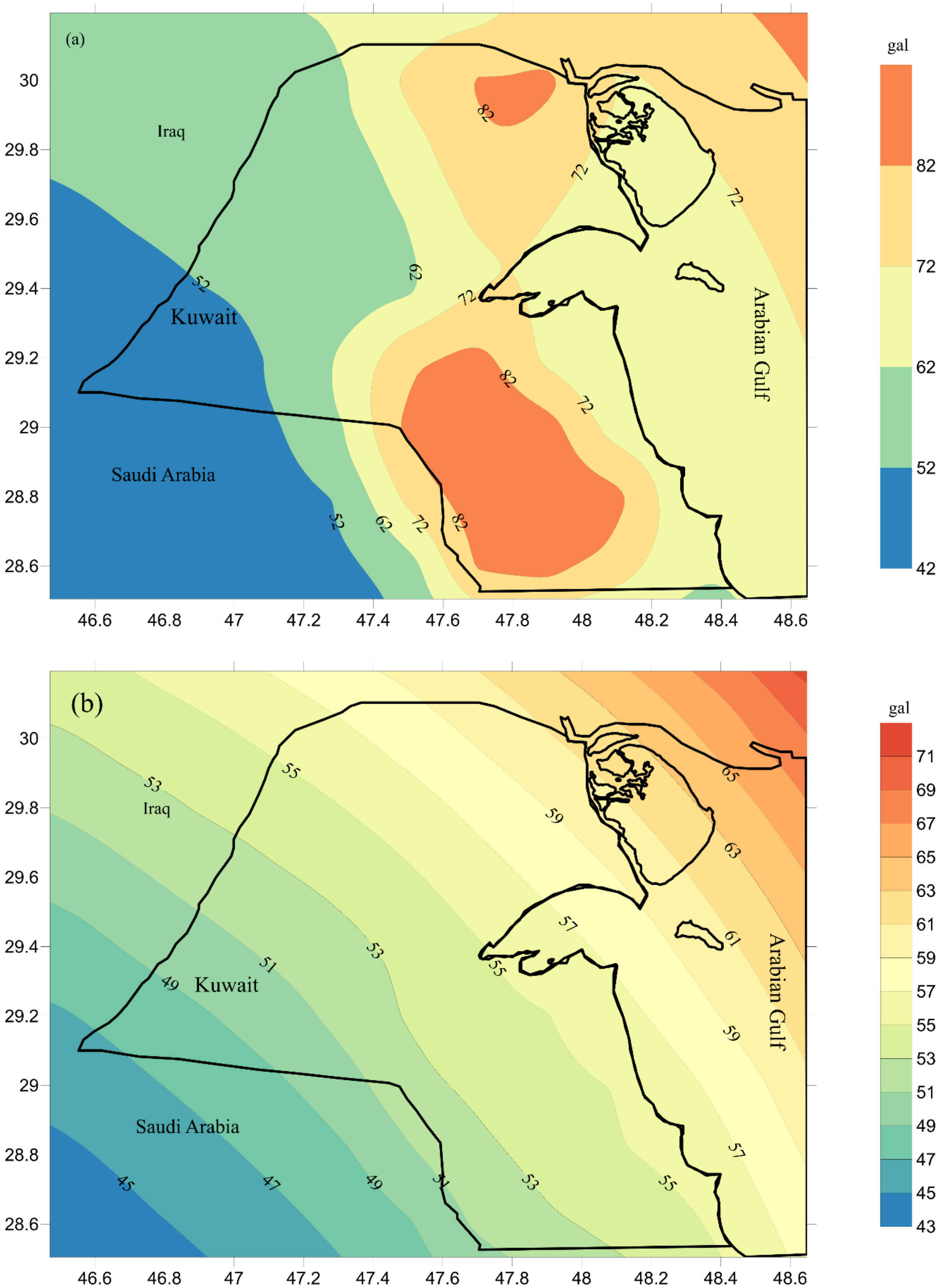

Fig.7. Seismic hazard maps of Kuwait for (a) 0.2 s and (b) 0.5 s at a return period of 475 years on the rock.

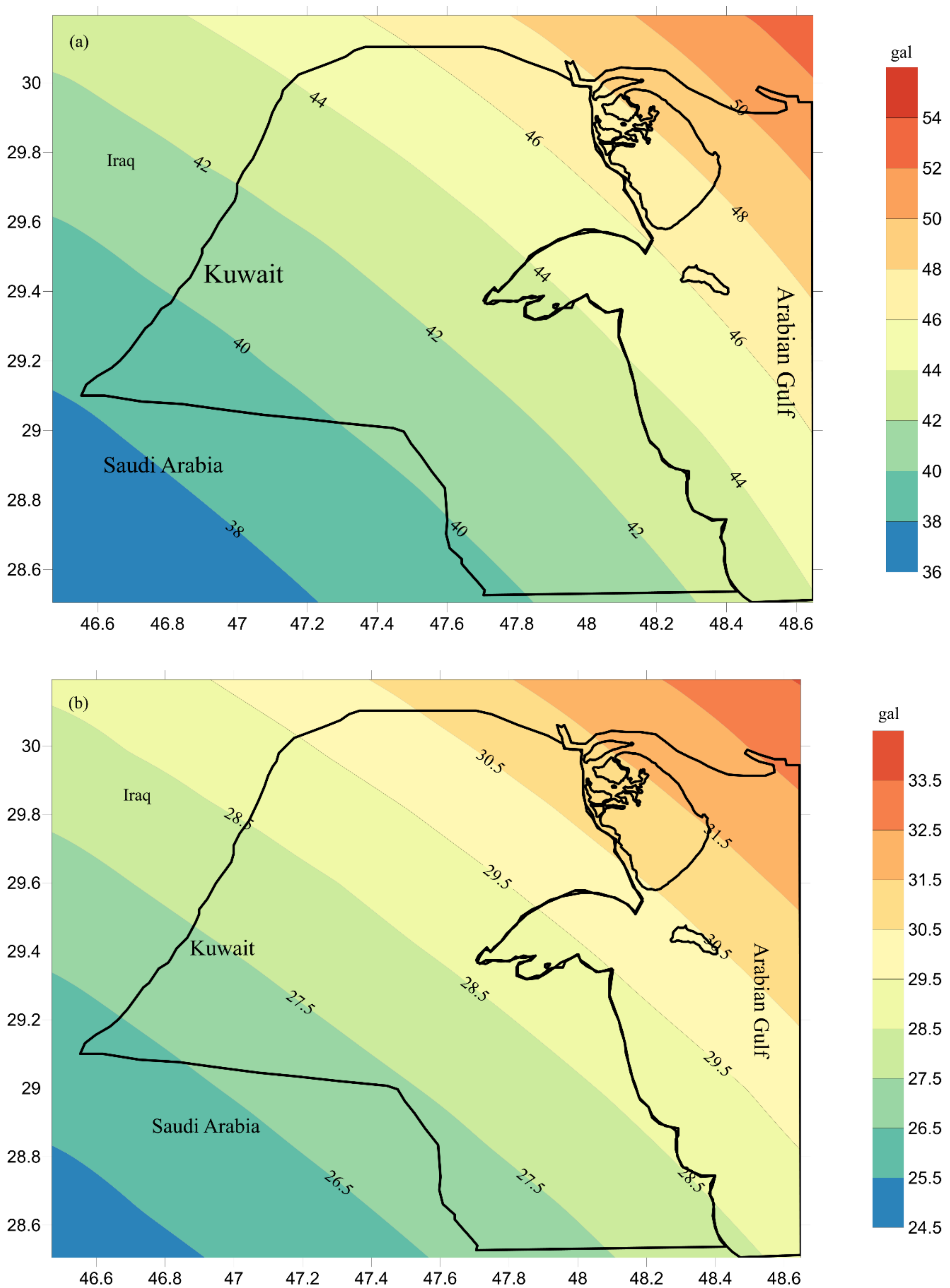

Fig.8. Seismic hazard maps of Kuwait for (a) 1 s and (b) 2 s at a return period of 475 years on the rock.

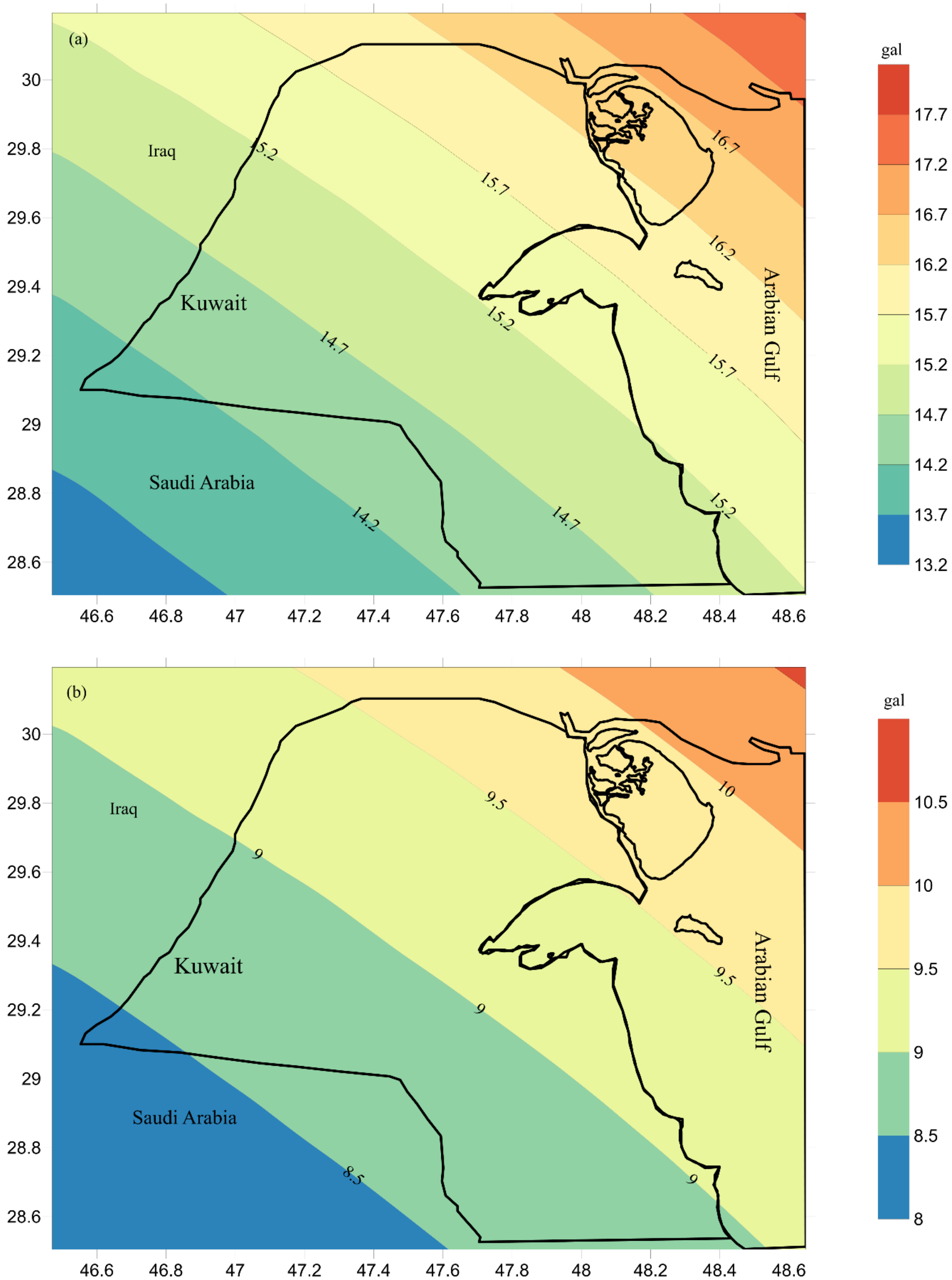

Fig.9. Seismic hazard maps of Kuwait for (a) 3 s and (b) 4 s at a return period of 475 years on the rock.

5.2. Uniform Hazard Spectrum

To determine the seismic hazard at spectral periods, the Uniform Hazard Spectrum or the UHS was used in the five different locations within Kuwait (Kuwait City, Salmiya Area, Sabriya Area, Managish

Area and Um Gudair Area), shown in (Fig.10), over a range of 0-4 seconds with return periods of 100, 475, 975, and 2475 years on bedrock for the seismotectonic model, as shown in (Fig. 11 to 15). According to the findings, acceleration values were seen to have an inverse relationship, increasing as the statistical likelihood of eclipsing ground motion declined over fifty years. The highest acceleration rate was observed at 0.1 seconds for each of the return timeframes, except for the Salmiya region, which had the highest acceleration at 0.2 seconds for the 100 and 475 second return periods. In terms of seismic activity, Um Gudair Area had the highest value, but it also posed a seismic hazard with 152.38 gal at a time frame of 0.1 seconds over 475 years. The statistics show that the maximum hazard is 2,474 years and the lowest is 100 years, with seismic hazards in the relevant locations dropping in the following order: Um Gudair Area, Managish Area, Sabriya Area, Kuwait City, and Salmiya Area. These findings are extremely important in earthquake engineering.

6. RELATION BETWEEN CURRENT STUDY AND INTERNATIONAL STUDY

Furthermore, when the findings of this study were compared with those of previous studies such as [2,44] a positive relationship was noted in Kuwait's regional seismicity structure. In addition, an accurate and thorough approximation of the seismic hazard over a 0.2° sized area was also maintained which accounted for teleseismic, regional, and local seismicity. These findings further reflect the relevant region's tectonics and seismic activity, supporting the estimations' precision and trustworthiness. Engineers can utilize these maps to create designs that are preventative of earthquakes, to carry out national and strategic initiatives, implement building codes and earthquake risk management. International studies did not take Kuwait into account in terms of seismic activity, (Earthquake Model of the Middle East (EMME)) [45]. This study added that there is weak to moderate seismic activity in Kuwait.

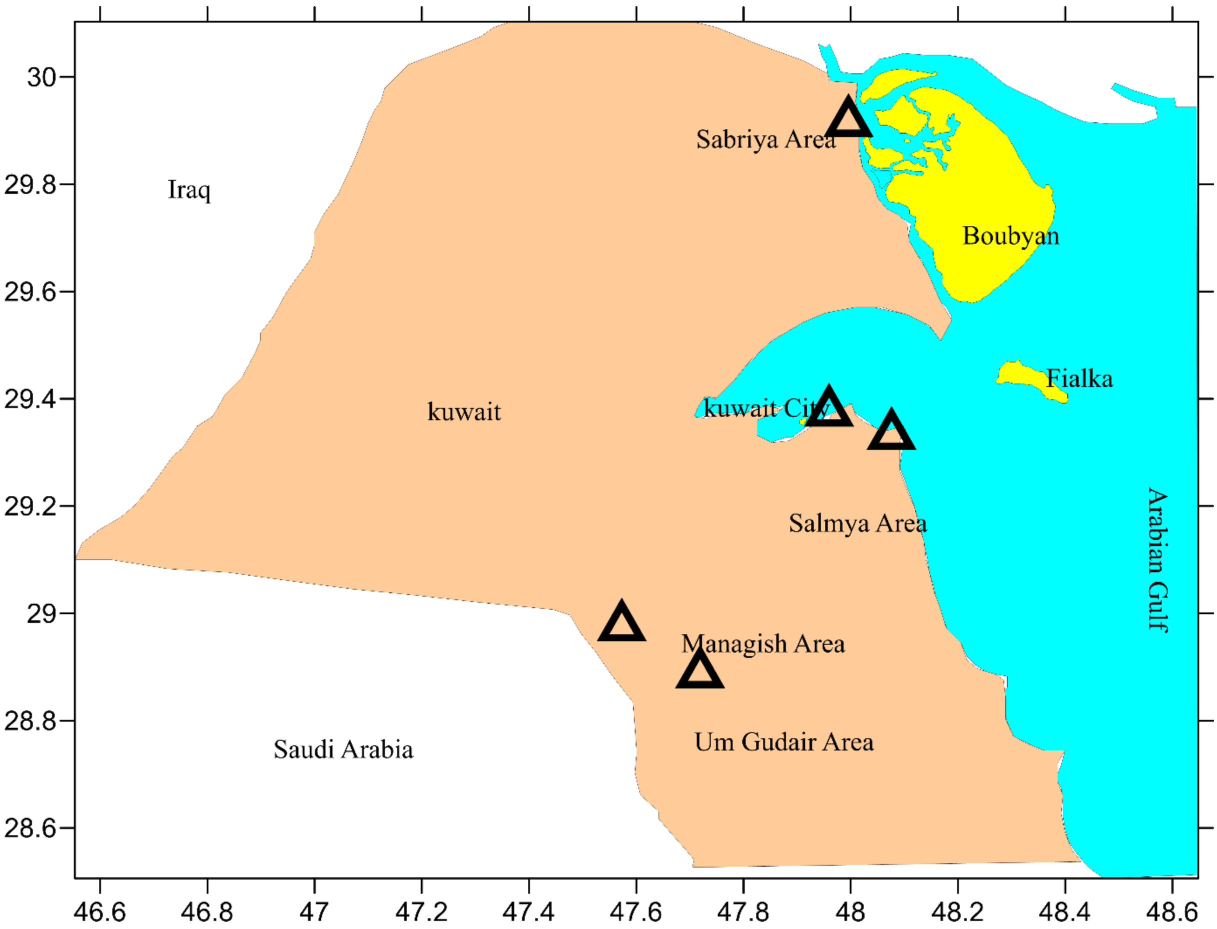

Fig.10. Study Areas in Kuwait (Kuwait City, Managish Area, Sabriya Area, Salmiya Area, and Um GudairArea).

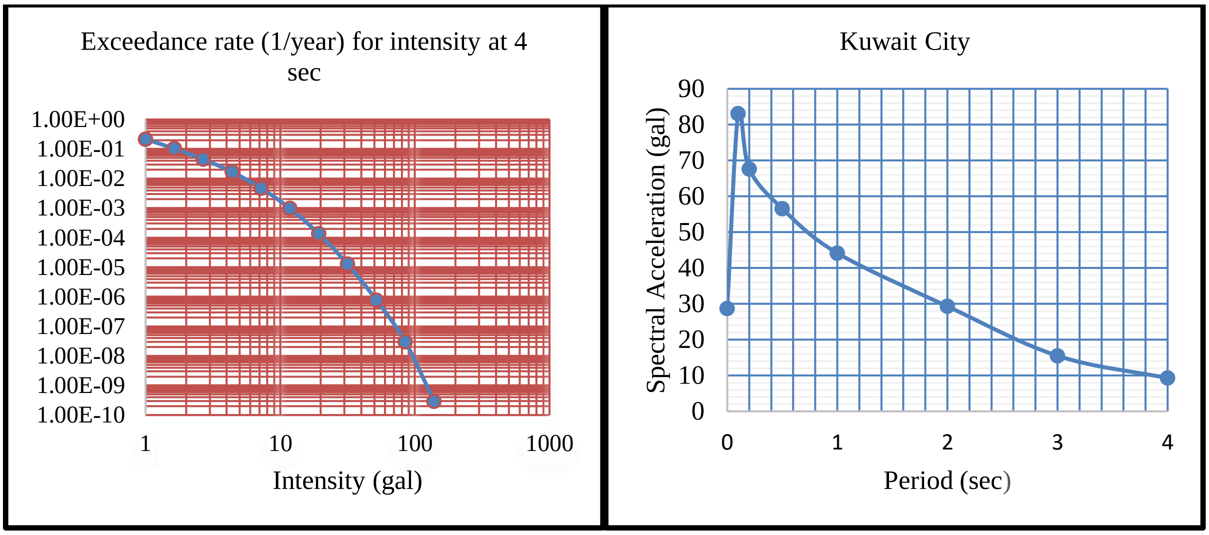

Fig.11. left: Exceedance rate for 4 sec at 475 years, right: UHS at 5% damped spectral acceleration values at return period 475 years on a rock for Kuwait City.

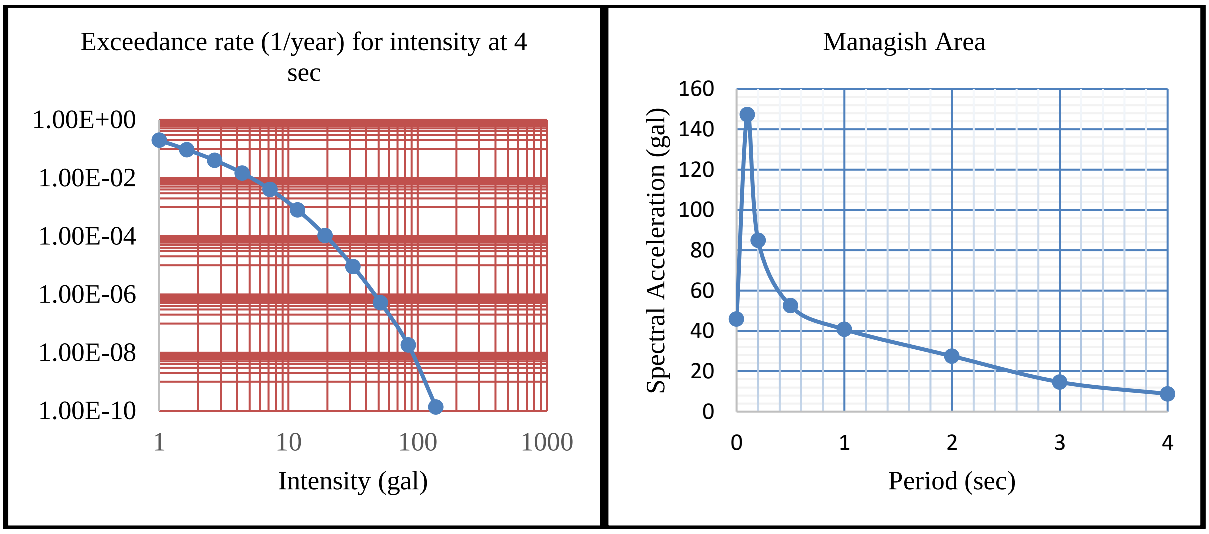

Fig.12. left: Exceedance rate for 4 sec at 475 years, right: UHS at 5% damped spectral acceleration values at return period 475 years on a rock for Managish Area.

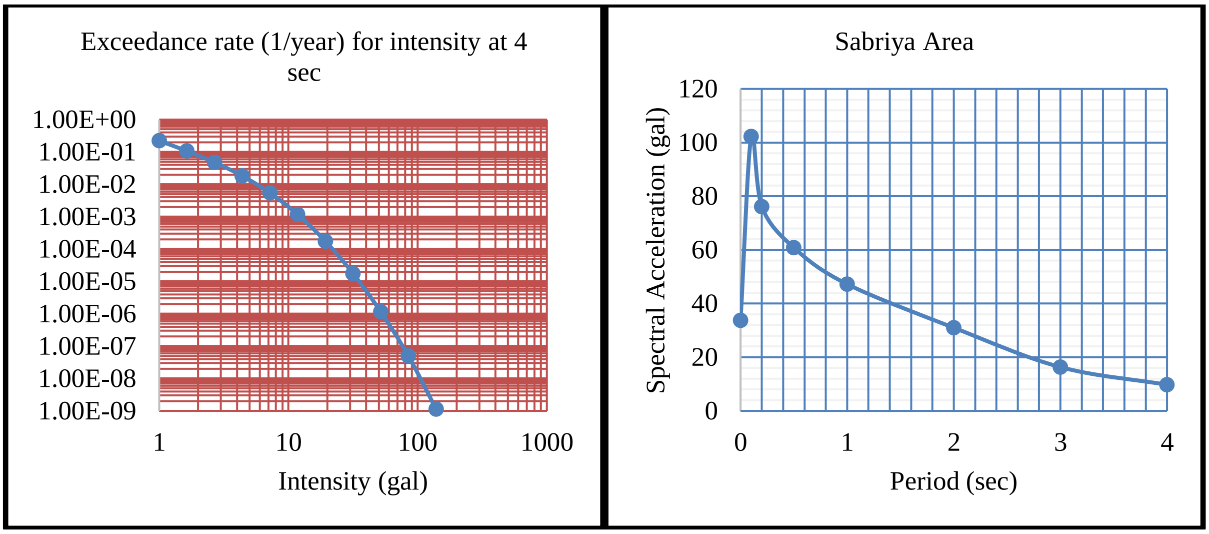

Fig.13. left: Exceedance rate for 4 sec at 475 years, right: UHS at 5% damped spectral acceleration values at return period 475 years on a rock for Sabriya Area.

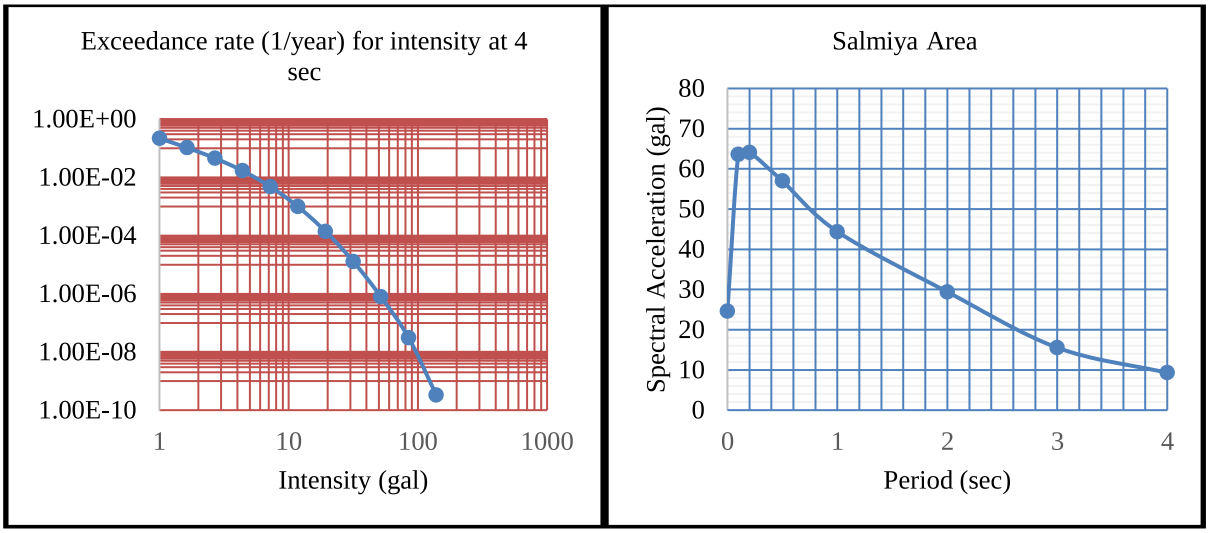

Fig.14. left: Exceedance rate for 4 sec at 475 years, right: UHS at 5% damped spectral acceleration values at return period 475 years on a rock for Salmiya Area.

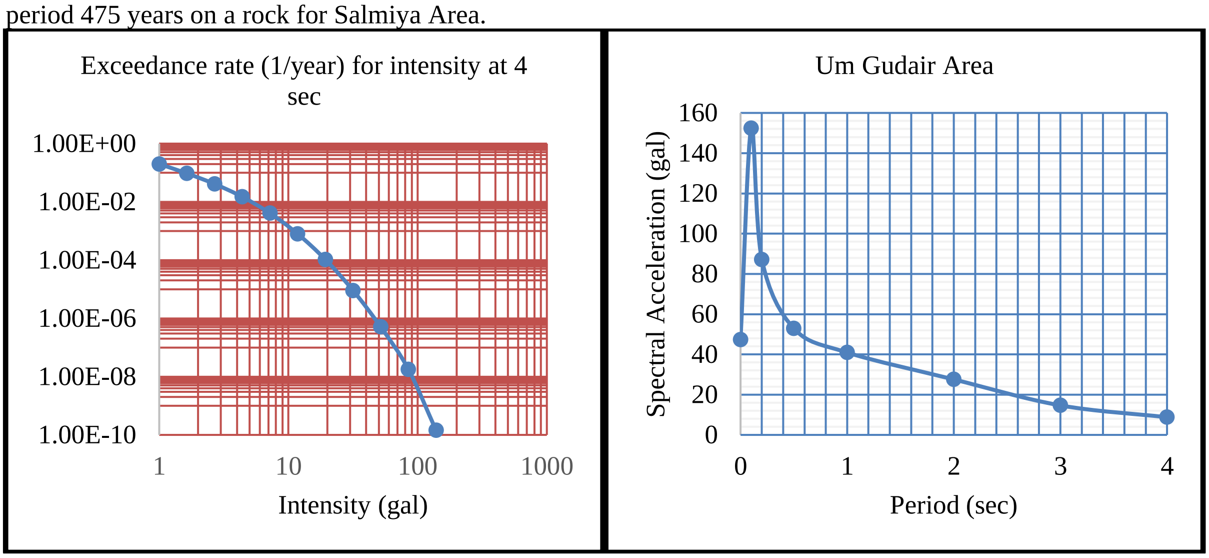

Fig.15. left: Exceedance rate for 4 sec at 475 years, right: UHS at 5% damped spectral acceleration values at return period 475 years on a rock for Um Gudair Area.

7. SUMMARY AND CONCLUSIONS

The current study involved the use of epistemic uncertainty seismic technique for the assessment of the seismic hazard for Kuwait. The technique was used before seismic risk assessment in Kuwait. An account of the earthquakes occurring between 1907 and 2019 obtained from several sources was entailed in the earthquake catalog which helped in determining the seismic conditions of Kuwait as well as the Zagros Thrust belt between 1907 and 2019 through PSHA.

The earthquakes and shocks incorporated in the catalog were filtered to exclude any foreshocks and aftershocks. This was followed by the certification of the catalog quality and consistency by assessing the Mc (magnitude of completeness). The seismic hazard analysis included the details of the earthquakes attributed with a moment magnitude of at least 4. Besides this, the catalog included all the earthquakes striking Kuwait and attributed with a moment magnitude of at least 2.5 between 1997 and 2019. The geophysical, geological, tectonic, structural, seismotectonic and seismological data obtained from various countries including Kuwait, Saudi Arabia, UAE, Iran and Iraq were utilized to develop a Seismotectonic model designed to determine the impact of seismic sources.

This was followed by the use of the maximum likelihood technique to determine the value of recurrence parameters β, b-value, and λ as well as the slandered deviations for each of these parameters. Predictions were made for the highest possible magnitude of earthquake expected to occur from each source. Then the evaluated maximum earthquake likelihood is used as an input parameter for the assessment of earthquake hazard. This gives an idea about the probable rock displacement anticipated to take place as a consequence of an earthquake. The seismic hazard was depicted with the help of maps at periods of PGA, 0.1, 0.2, 0.5, 1, 2, 3, and 4 seconds for return periods of 100(equating to 39.3% PE), 475(indicating 10% PE), 975(5% PE) and 2475 years (2 % PE) where PE denotes the probability of exceedance of ground motion in 50 years.

Low to moderate seismic activity of Kuwait is evident in the drawn maps with the south-western areas of Um Gudair and Managish oil fields attributed with the highest seismic activity. Moreover, the northeastern region of Kuwait housing the Sabriya oil field was found to be attributed to high seismic activity. Hence, the presence of induced seismicity is apparent in these areas. Both the short spectral periods and long return periods depicted high acceleration. Moreover, hazard was determined through the evaluation of UHS at 5 significantly important regions at various spectral periods from 0 to 4 seconds for return periods of 100, 475, 975, and 2475 years on bedrock. The spectral period of 0.1 seconds was found to be attributed to the highest acceleration. However, Salmiya Area was an exception which was attributed with an acceleration of 0.2 seconds for certain return periods in the seismotectonic model.

According to the outcomes of the model, the south-western area of Um Gudair resting on the eastern part of the Arabian plate was attributed with the highest seismic activity and posed the greatest danger of occurrence of an earthquake. In general, the results showed that the most severe impact on the five sites is dominated by nearby medium-size earthquakes at the short spectral period of 0.1 seconds, which means that small risks can be expected due to the short duration and low energy content. However, they are dominated by nearby large size earthquakes at the long spectral period of 2 seconds, which means that high risks can be expected due to the long duration and high energy content. The results of this study are consistent with the seismicity and tectonic setting of the study area. The reliable estimates of acceleration at variable spectral accelerations and different return periods guide an earthquake engineer to build safe structures that can resist ground motion in the event of an earthquake. These results can be very helpful to create a unified seismic code for Kuwait.

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